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ABSTRACT

This manual provides suggestions for investigating simple machines and the teaching of certain basic concepts which pertain to them. Many of the lessons are designed to be used with the commercially available LEGO kits, in an effort to teach concepts in a way in which students must translate pictures shown in two dimension into three-dimensional models. The guide lists the scientific concepts and principles being addressed, along with the unit objectives and other materials which are needed. The major portion of the guide describes 12 lessons, which deal with: (1) an introduction to the simple machines unit; (2) work and levers; (3) friction; (4) inclined planes and screws; (5) wheels and axles; (6) belt transmission (as it applies to multiplying force and speed); (7) gears and gear ratios; (8) the transmission of motion; (9) centrifugal force and motion; (10) pulleys; (11) steering mechanisms; and (12) mechanical advantage. Included is a set of test items that can be used for evaluating student progress. (TW)

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SIMPLE MACHINES CURRICULUM

Prepared by: Department of Curriculum and Instruction
Anoka-Hennepin Independent School District No. 11
Coon Rapids, MN 55433

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LEGO[R] EDUCATIONAL SYSTEM
SIMPLE MACHINES UNIT

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FOREWORD

The Simple Machines Teacher's Manual suggests methods for the investigation of simple machines and the teaching of certain basic concepts which help us understand them. The specific concepts taught in this unit are shown on the following graphic. It is the intent of this unit to help pupils learn these concepts by using LEGO^{R} TECHNIC materials, wherever possible.

This manual was prepared by a writing team in the Anoka-Hennepin Independent School District No. 11, Minnesota. In determining the format of District No. 11's Simple Machines Teacher's Manual, which augments the commercial LEGO manual Teacher's Guide to TECHNIC I, two specific decisions were made. One was that some material in the LEGO manual would be optional because either it did not directly contribute to the goals of a specific lesson, or it was determined to be counterproductive to reaching those goals. (For instance, on page 10 of the LEGO manual, it is suggested that the pupils rearrange the parts from largest to smallest. It is our opinion that this exercise would neither contribute to understanding the kit nor help in understanding any of the concepts to follow.) A second decision was to rearrange the order in which the Cards are to be used. These rearrangements were made so that Cards relating to specific concepts were grouped together. The Notes section of the lessons or the body of the lesson will occasionally contain references to the LEGO manual.

One of the advantages of using the LEGO materials to teach the desired concepts is that pupils must translate pictures shown in two dimensions to models which are three-dimensional. In so doing, pupils make decisions regarding which pieces of equipment need to be used and where these pieces are to be placed. As more advanced models are built, more complex mental perceptions are required.

The complexity of the constructions and the concepts involved should quickly disabuse pupils of the idea that LEGO materials are toys and that students are "playing." It is advisable to immediately establish a serious atmosphere when introducing the unit.

Scientific Concepts/Principles

Practical Applications

Simple Machines

Work = force x distance
Mechanical advantage
Energy: kinetic and potential
Friction
Mechanical advantage
Centrifugal force
Transmission of force
Transmission of motion
Stability

Levers
Pulleys
Wheel and axles
Gears, belts
Inclined plane, (wedge)
Parallel and trapezium steering
Screw

OBJECTIVES FOR THE SIMPLE MACHINES (LEGO) UNIT

During this unit, the pupils will:

1. Understand that humans have developed simple machines to make their work easier.
2. Know the five simple machines and their characteristics.
3. Be able to recognize the practical applications of simple machines.
4. Recognize that simple machines make work easier, but do not save work.
5. Recognize that a simple machine may (a) change the direction of a force, (b) multiply a force, (c) transfer a force from one place to another, or (d) increase the speed with which work is done.
6. Be able to use gears/belts in combinations to transfer/multiply force.
7. Recognize that friction is a factor in the operation of all machines.
8. Recognize that friction has advantages and disadvantages.
9. Recognize that machines provide a mechanical advantage, i.e., a way to measure the degree to which work is made easier.
10. Be able to transfer two-dimensional drawings to three-dimensional constructions.

ADDITIONAL MATERIALS NEEDED

Classroom Sources (Teacher, Pupils, Custodial)

Bars of Soap
Bolts
Calculators
Crayons/Markers
Jar Lids - or something circular to trace around
Knife
Marbles
Paper Clips
Screwdriver
Scissors
Various Screws

District Sources (In Kit)

Nails
Sheet Metal Screws

Optional Demonstration Items

Hand egg beater
Pulleys of various sizes
Wedges for splitting wood

Lesson 1: Introduction to the Simple Machines Unit (Cards 1 and 2)

NOTES

GOAL/RATIONALE

The purpose of this lesson is to show the pupils the necessity for meticulously arranging and storing the parts in the LEGO^{R} kits so that the kits are ready for continued use. You may relate this activity to the type of activity scientists must do in order to efficiently work in laboratories with equipment. Many pieces are quite small. Therefore, the pupils should be cautioned that they are responsible for making sure all parts are in place after each work session.

Kit Introduction: Housekeeping Details

The following suggestions are based upon teaching experience with this unit and are offered for your consideration.

1. Pupils should work in teams of two. The process by which team members are selected or assigned is deferred to the judgment of the classroom teacher. However, it is recommended that the same team be kept together for the duration of the unit if at all possible.

2. Each kit is identified with a number on the lid and in the well under the item called the building plate. Each team should be assigned a kit and expected to use the assigned kit for the duration of the unit.

3. The Kit Content Sheet and the Team Kit Care Record are provided to assist in the maintenance of the kits.

   The Kit Content Sheet has each space labeled and marked by the number of pieces in each slot.

   The Kit Care Record has space for regularly (daily) checking that the kit was intact when checked in.

4. Insist that unused pieces be returned to the proper location in the kit as pupils work. Working from the kit is easily done. Experience has shown that parts left on desk tops are easily misplaced.

5. Multiple copies of each card are provided so that one is available to each team.

6. Designating a person as "Kit Checker" at the conclusion of each work period makes inventorying easier.

ANTICIPATORY SET (Teacher demonstration and pupil participation)

Have constructed for display one of the models pictured on a LEGO^{R} card. (Because you are going to have to make it from a pupil kit, choosing a construction which can be easily taken apart is wise. The pupil team has to count those parts with its kit later on in this lesson.) Tell the pupils that this is an example of the kind of constructions they will be making. From this construction, they will be learning some of the basic principles of simple machines.

OBJECTIVES

At the end of this lesson, the pupils will:

1. Become familiar with the organization and features of the LEGO kit.

2. Know the labels for specific parts.

3. Correctly arrange the storage of items in the kit.

4. Differentiate between rigid and movable connections.

5. Assemble constructions by following the pictures shown on Card 2.

GUIDED PRACTICE

1. Distribute the kits to each team. Give each team a Kit Content Sheet and a Team Kit Care Record. Explain that each team is responsible for having the Care Record initialed by you (or a designated checker) each time before putting the kit away for the day. Tell them the Kit Content Sheet specifies the number of parts and their storage areas. They will be using this soon.

2. Distribute Card 1, one card per team. Demonstrate how pieces can be removed as shown on the back of Card 1. The lid must be slid out. Then it should be placed in the back groove to serve as a stand against which the card can rest.

3. Using the pictures on Card 1 and the labels and numbers indicated on the Kit Content Sheet, have the pupils check off each item found in the kit. Point out that there are particular pieces stored under the large green building plate. The label for each piece is specifically mentioned on the Kit Content Sheet. They should bring to you any extra pieces they find or tell you of any missing pieces. Stress that they are responsible for the accuracy of the kit.

4. Review with the pupils the vocabulary for particular parts. In later construction, knowing the identifying names will enable pupils to be more precise when they are asking questions or communicating problems or solutions to each other. As a teacher, you can also give more precise help when asked. (Compare with computer studies where students need to know words such as "Interface, Boot Up, Menu.")

   Show the pupils how stud beams and stud plates are differentiated by the number of studs per row. "Plates" are flat and have no holes running through from side to side. "Beams" have holes from side to side.

Help the pupils understand that an inference is based on their best guess of what is or should be. Specific designs are not pictured from all angles, but based on what is shown, the pupils can determine what pieces are necessary to complete the constructions.

5. Distribute Card 2 and have the pupils put together the various pieces as shown on the front cover. Discuss how to determine which pieces to use. In some cases, you have to think of the angle from which the piece is being viewed. In other cases, you may have to infer what has to be there in order for the visible pieces to hold together. Note also that there are small numbers by the axle pictures which identify the size of axle to be used. (The number corresponds to the number of studs, on the green building plate, which the axle will cover.)

On page 11 of the LEGO® Teacher's Guide are follow-up activities to use when those who rapidly complete assigned models are finished. It is advisable to set some guidelines for "free time" activities. Constructions built during "free time" should relate to the particular concept which the pupils are studying at the time. In this case, the three activities in the teacher's manual are rigid constructions. You may add an extra challenge by asking for modifications which would be movable, e.g., the bars on the cage could swing out, etc.

The kit lid is numbered, as is the well under the green building plate. For some groups you may find it advisable to be sure lids and bases always match.

As the teacher, you will need to decide how long or whether constructions are to be left intact. Past experience has shown that pupils do not object to dismantling a completed construction at the end of class. If you have a secure area, partially finished work can be left intact. However, checking kit content becomes more difficult.

INDEPENDENT PRACTICE

Follow this procedure with the inside pages. (Pupils familiar with LEGO construction can help others if you feel this is necessary.) By "walking through" the various models on the inside cover, you can (1) see which pupils easily handle the procedures, and (2) identify those who are having problems. You may want to consider reassigning different partners where you find problems in construction occurring.

Once successful constructions are made using the middle pages of Card 2, ask the pupils to note where there were "rigid constructions" and where there were "movable structures." Explain that rigid constructions are those which do not shift or move.

Provide opportunities for the pupils to construct at least one of the models on the back page.

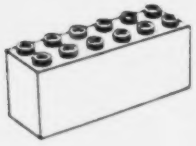
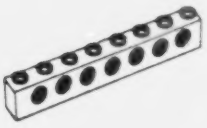
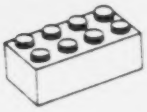
CLOSURE

Before dismantling and replacing the parts in the kit, take time to have the pupils hold up various pieces as you call out the official names (i.e. universal joint, piston, bevel gear). They should also be able to identify which parts of the construction shown on the back page are rigid constructions, and which are movable constructions.

Before putting away the kits, or during the time the kits are being checked in, you may wish to have the pupils record several sentences summarizing their discoveries/reactions for this day's work; e.g., "From today's work I found that . . ."

Tell the pupils they are responsible for keeping a lab book in which to record notes and data as they work. In succeeding units, there will be some pupil information sheets which they must keep for reference.

When the kit is ready to be handed in, both team members' names should be on the check-in form along with the number of the kit they are using. This is to be their kit throughout the unit. The "checker" should scan the kit and write his/her initials in the appropriate column. This checksheet and the content inventory sheet should stay inside the kit at all times.

ELEMENT	NUMBER	NAME	COLOR
	1	Weight element (Mass 54 gm)	Red
	1	8-stud beam	Red
	4	2 x 4-stud brick	Blue
	8	Turntable	Blue/Grey
	4	**Tilting bearing** (assemble before placing in box)	Blue
	1	Angular plate	Blue
	1	Universal joint	Grey
	1	Piston	Grey
	4	Gear rack	Grey

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ELEMENT	NUMBER	NAME	COLOR
	4	1 x 3-stud plate	Red
	4	1 x 4-stud plate	Red
	2	1 x 6-stud plate	Red
	2	1 x 8-stud plate	Red
	4	Tire (assemble before placing in box)	Black
	4	Crosshub	Grey
	1	Steering wheel (Pulley)	Grey
	2	Pulley wheel	Grey
	1	String	Black

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ELEMENT	NUMBER	NAME	COLOR
	2	40-tooth gear-wheel	Grey
	3	24-tooth gear-wheel	Grey
	6	8-tooth gear-wheel	Grey
	2	Crown wheel (24 Teeth)	Grey
	2	Bevel gear (14 Teeth)	Grey
	8	Piston rod	Grey
	20	Connector peg	Grey
	20	Bushing	Grey
	12	2-stud beam	Blue
	12	4-stud beam	Blue

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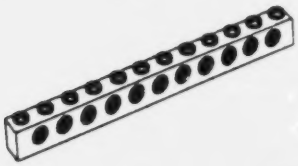
ELEMENT	NUMBER	NAME	COLOR
	2	6-stud beam	Blue
	2	8-stud beam	Blue
	2	12-stud beam	Blue
	4	16-stud beam	Blue
	4	Axle, 4-studs long	Black
	4	Axle, 6-studs long	Black
	2	Axle, 8-studs long	Black
	2	Axle, 10-studs long	Black
	2	Axle, 12-studs long	Black

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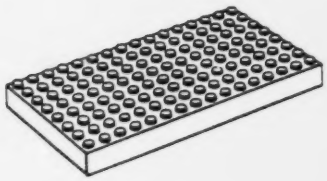
ELEMENT	NUMBER	NAME	COLOR
	4	2 x 4 plate with holes	Red
	4	2 x 6 plate	Red
	2	2 x 8 plate with holes	Red
	1	Building plate, 8 x 16 stud	Green
	4	Rubber band	Black

Note: The extra elements, string, rubberbands and some 8 toothed gearwheels can be stored in the compartment under the green building plate.

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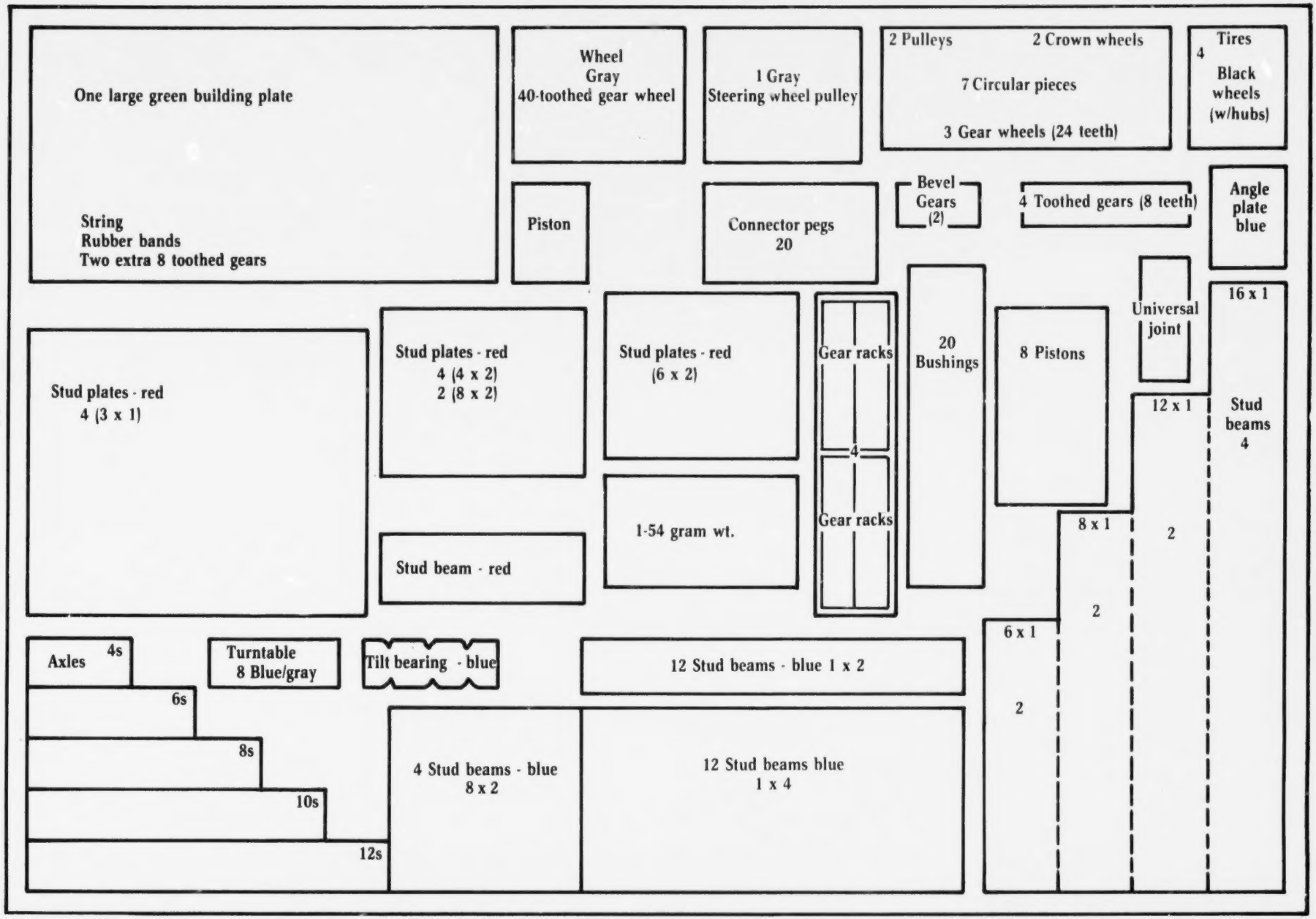
TEAM KIT CONTENT RECORD



TEAM KIT CARE RECORD

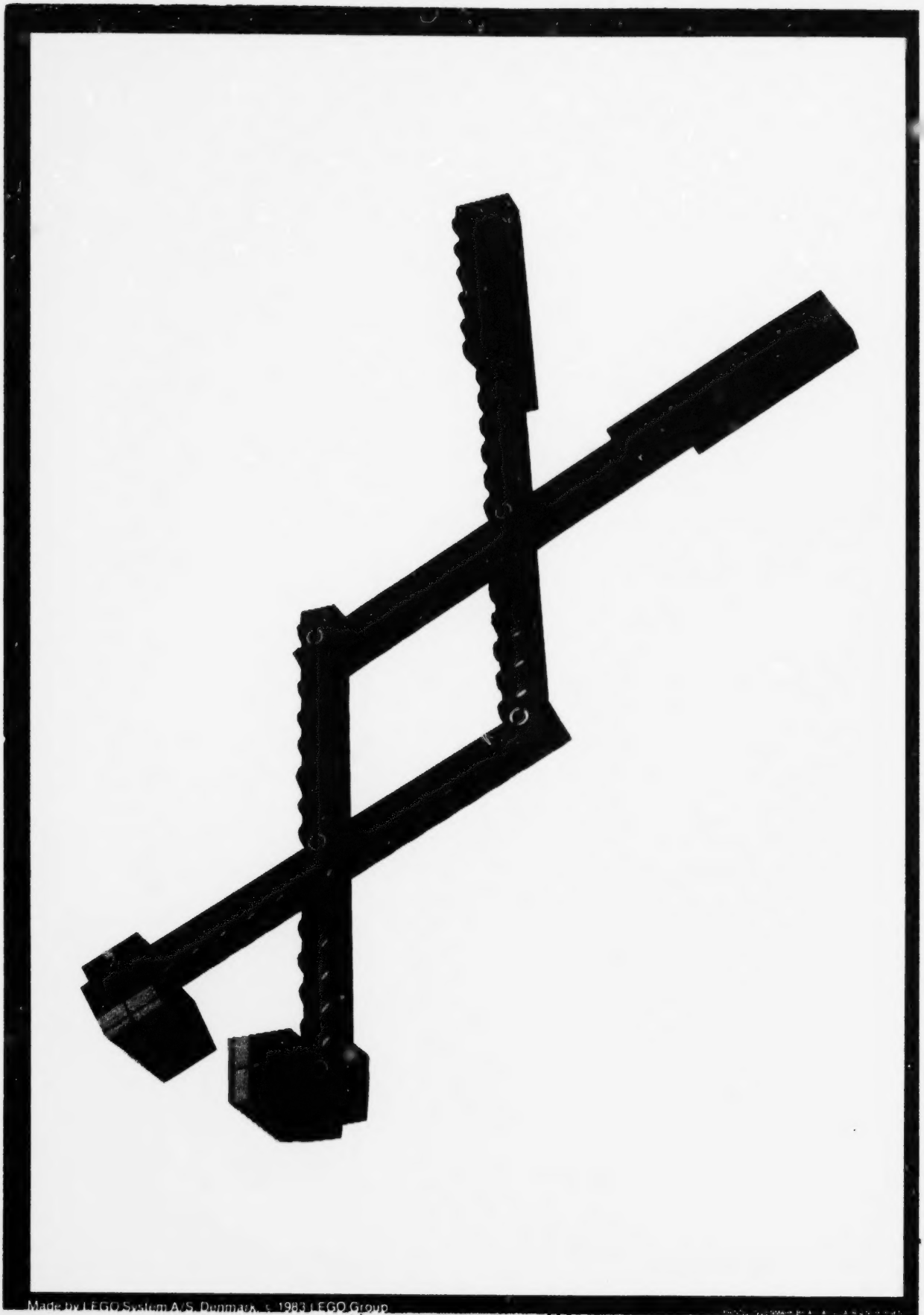
Team Members _____

Kit number _____

Date	Kit Complete (Teacher/Checker's Initials)	Name of missing pieces	#

Originally missing: _____

_____



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NOTES

GOAL/RATIONALE

The goals of this lesson are to develop the scientific concept of work, to show that simple machines make work easier, and to introduce levers as one kind of simple machine which helps make work easier.

Concept Label	Concept Characteristics	Examples	Non-Examples
Machine	A machine is a device which makes work easier by changing the direction or distance through which a force moves. The following are simple machines: lever, inclined plane, screw, pulley, and wheel and axle. A compound machine is made up of two or more simple machines working together.	Baseball bat Hockey stick Ice skates	Book Flower pot Shoe Baseball mit Hockey puck
Work	The scientific use of the term **work** relates an amount of force applied to an object moved a certain distance. The two conditions are force and distance. An effort (force) that does not move the resistance is not considered work. Computation of work accomplished is determined by the formula Work=Force multiplied by Distance moved (W=FxD). If the object does not move, then W=Fx0, hence no work is done.	Pushing a cart down the hallway. Lifting a box to the top of a table.	Pushing on a solid wall.
Lever	A lever is a simple machine. It can be defined as a bar that moves on a fixed point. The point on which the bar moves is called the fulcrum. When an effort is applied to a lever, a resistance can be overcome. Therefore, a lever makes work easier. There are three classes of levers based upon where the fulcrum is in relation to the effort and the resistance.	Scissors Wheelbarrow Fishing rod Ice tongs	Sheet metal screw Stairs Axe blade

Part A: Work

ANTICIPATORY SET (Pupil Activity and Teacher Demonstration)

Have pupils take out a book (social studies or some other common book), a small piece of paper, and a pencil. Tell them to record "yes" or "no" to each of the following questions:

1. Ask them to lift the book from the desk top. **Is work being done?** (Yes)
2. Hold the book perfectly still at arm's length. **Is work being done?** (No)
3. Push the book across your desk top. **Is work being done?** (Yes)
4. Have all of the pupils, or select a few volunteers, go to a nonmovable wall space and push as hard as they can. **Is work being done?** (No)

OBJECTIVES

At the end of this lesson, the pupils will:

1. State an example of work and a non-example of work.

2. Use the formula W = F x D to compute the amount of work done.

DIRECT INSTRUCTION

Explain to the pupils that a scientist defines work as applying a force to move an object through a distance, i.e., Work = Force x Distance. Therefore, only questions No. 1 and 3 above could be correctly answered yes. (Being tired, even exhausted, is not scientifically sufficient proof of work accomplished. Therefore, holding the book and pushing on the nonmovable wall did not accomplish work according to the scientific definition.)

In the English system of measure, force is measured in pounds and distance is measured in feet. Therefore, the unit for recording the amount of work done is foot-pounds.

In the metric system of measure, force is measured in newtons* and distance is measured in meters. Therefore, the unit for recording the amount of work is done in newton-meters. The term newton-meters is also called joules (ju ls).

*To measure newtons, you need a metric scale specifically marked in newtons.

For this quick check, you can use the whole class response procedures where every pupil holds up the answer written large enough on a piece of paper to be easily seen by you. Do not permit the answer to be shown until you direct the pupils to do so.

One method of illustrating how work is measured scientifically is to have the pupils lift their book two feet above their desks. If you assume that each book weighs one pound, then two foot-pounds of work has been done. W = F x D or W = 1 lb. x 2 ft. If two books are lifted three feet, six foot-pounds of work are done, etc. When working with the formula W = F x D, explain to the pupils that force will be measured in pounds, distance will be measured in feet, and the total amount of work done is recorded in foot-pounds. (It was decided to use these familiar terms rather than the metric measurements of newtons and meters.)

Ask the pupils to demonstrate one foot-pound of work being done by lifting their books one foot above their desks. Suggest that they demonstrate two foot-pounds of work (lifting one book two feet or lifting two books one foot).

To check their understanding of the work concept, ask the pupils:

1. **Which requires more work: (a) lifting three books three feet, or (b) lifting two books four feet?** (3 x 3 = 9 foot-pounds versus 4 x 2 = 8 foot-pounds; therefore, a is the correct response.

2. **If you raised a ten pound box four feet, how much work would you have done?** (10 x 4 = 40 foot-pounds)

3. **Which requires more work: (a) lifting two books three feet, or (b) lifting six books one foot?** (Both result in six foot-pounds of work, so you should get some puzzled expressions.)

Part B: Levers

ANTICIPATORY SET (Discussion)

Building on the scientific definition of work, list ways in which humans make work easier. (A clarification of "making work easier" versus "saving work" will be developed later.) The idea of "machines" should evolve from the discussion - or you can devise questions to elicit this response: How do you take the cap off a bottle? How do you cut paper cleanly? How do you remove nails that have been pounded into a board?

OBJECTIVES

The pupils do not need to know which lever is type one, type two, or type three. However, they should understand that, although the fulcrum's position is changed, the tool is still a lever.

At the end of this lesson, the pupils will:

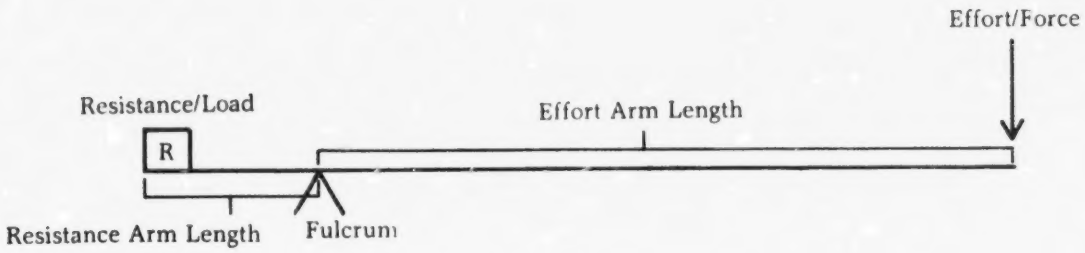
1. Describe levers.
2. Identify examples of levers in common objects.
3. Recognize various forms of levers.
4. Understand and correctly use the terms fulcrum, effort force, effort arm, resistance/force, and resistance arm.
5. Demonstrate that a lever multiplies force by computing the amount of work done using the formula W = F x D.

DIRECT INSTRUCTION

It is appropriate at this time to introduce the term **simple machines.** Through the ages, humans have devised various devices to make their work easier. Each of these devices, or simple machines, has a particular advantage and specific characteristics that make it identifiable. Compound machines are, by definition, combinations of various simple machines.

The various models are color coded within circles. They become progressively more difficult. White is the simplest. For easy reference, we shall refer to them as white models, yellow models, and red models.

Distribute Card 4. Have the pupils set up the white model at step 1. Have them move the axle so that it is in the middle of the 16 x 1 beam, i.e., it is balanced. Have them place the red 54 gram weight on one end. This weight will be called the resistance force or load and is designated by the letter R. The weight will cause the balance to tip. **What must be done to again balance the beam?** Another 54 g. weight must be placed on the opposite end. This acts as the effort force. Have teams share a weight and get one of their beams to balance. Place a graphic such as this one the board or overhead also:



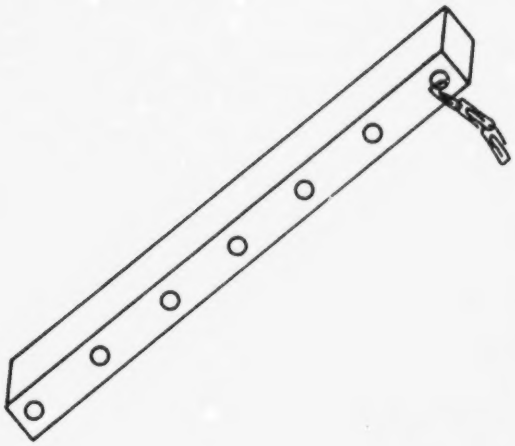
Point out that in their models, work was done as the 54 g. weight (R) was raised from the desk top to the balance point. Have them put three 2 x 1 beams on the corner of the building plate nearest the original red beam as a guide for measuring distance. It is important that they understand that the work done is measured by the distance the load (R) moves. Remove the "effort" red weight and have the team members keep the beams in balance by pushing down with their fingers on the effort arm. Tell them to note the feel of how much effort they are exerting.

GUIDED PRACTICE

(Keep the above drawing visible for reference.) Using Card 4, have them change the white model to look like step 2. Tell them the model they have constructed is a **lever,** one kind of simple machine. It is a common device for making work easier. Illustrate how the lever relates to the "work" concept. Using one of the models constructed, tell them that the red weight is the "load" or "resistance"; the arm on which you press down is the "effort arm" and your finger is applying the "force." The axle is the fulcrum or pivot point.

Ask the pupils to press down on the end of the effort arm with enough force to raise the 54 gram weight so that it is level with the end of the effort arm. **Did it take more or less effort than when the fulcrum was in the middle?** (less) Then have them change the position of the fulcrum (axle) so that the effort arm is shorter. Note the difference felt in the amount of force it now takes to raise the weight. Have them again change the fulcrum so that the effort arm is shorter still. Again, raise the weight. (Although they are not measuring the difference in the amount of force required at this time, the feel of raising the weight is significantly different so that the pupils will be able to notice it.)

Have the pupils record what happened when the fulcrum position was changed, e.g., "When I moved the fulcrum farther from the weight, the weight was harder to lift.



If the pupils set the lever on top of a thick book, such as a dictionary, it will make the measuring easier because there will be room for the clips to hang without touching the desk. Or, they can move the lever to the edge of the desk so that the arm hangs over the edge. Just be alert to clips falling on the floor.

The purpose of making this record is to show the relationship of effort force to effort arm distance, i.e., as one becomes less the other becomes greater. Force will be measured in number of paper clips used; distance is measured in number of holes from the fulcrum to the end of the effort arm. These numbers cannot be multiplied together to find the amount of work done.

By moving the fulcrum, I made the effort distance shorter. Therefore, the effort force had to become more."

Ask the pupils to suggest a way to make the weight even easier to raise. If no one offers a solution, suggest that they make the effort arm longer by using another 16 x 1 stud. (See LEGO^{R} Teacher's Guide, page 15, for a small picture of this.) Give the pupils some time to explore the change and to feel the difference in force needed to lift the weight. Point out that now that the effort arm is longer, the effort force needed is less so the weight is even easier to raise. Call their attention to the distance the end of the effort arm has moved, i.e., the longer the effort arm, the greater the distance moved.

INDEPENDENT PRACTICE

Using the longer armed lever constructed above (two 16 x 1 studs), have the pupils hang a small paper clip (uncoil it so one end goes through the beam hole) from the end of the effort arm. Then have them actually record the number of small paper clips it takes to raise the weight to the balance point. (Don't include the clip, used as a hook, in your count.)

Next, they can change the fulcrum by moving the axle two holes away from the weight. Again, record the number of clips used. This procedure can be repeated several times. Have the pupils record the results each time. Study Master #1 for recording the results (data) is enclosed. Your data may look similar to this.

Weight Lifted	Force (in paper clips)	Distance (in holes from fulcrum to end of effort arm)
54 g	10	25
54 g	20	23

CLOSURE

The purpose of this investigation was to demonstrate the relationship of distance and force to the amount of work done. Therefore, after the data is recorded, ask the pupils:

1. **What happened to the number of clips required to raise the weight as the effort arm became shorter?** (There were more clips needed.)

2. **What does this tell you about the relationship of force to distance in doing work with a lever?** (As

the distance becomes less, decreases, the force required to do the same amount of work increases.)

Have the pupils record a summarizing statement on their record sheets (lab notebooks) before proceeding to the next investigation.

ADDITIONAL GUIDED AND INDEPENDENT PRACTICE

Have the pupils construct the yellow model on Card 4. Ask them to identify the fulcrum (the place where the two bars of the scissors-like object join.) Have them point to the effort arm and the resistance or load (the end where something could be held). This model is also a type of **lever**.

Give them time to investigate the feel of the difference in effort required to close the pincers if they change the fulcrum. Some students may also want to extend the handles to investigate how this affects the effort needed.

Ask the students to relate this device to actual objects used in the home (some tongs, shears, scissors, etc.).

Now have the pupils build the red model (wheelbarrow). Again, have them identify the fulcrum (the tire-axle point). Note this time the load or resistance is between the fulcrum and the effort. However, the device is still a **lever**.

Give the pupils time to investigate the differences in effort needed to raise the weight if the weight is moved farther and farther from the fulcrum.

At this time, give the pupils Information Sheets I a, b, and c on levers. The diagrams on these sheets will help them see the different placements of the fulcrum in various kinds of levers.

Using the pictures on the inside of Card 4, have the pupils point to the (1) fulcrum, (2) effort arm, and (3) resistance or load.

Page 15 of the LEGO^{R} manual has a form which you may wish pupils to use as a way to record the use of levers in real life.

Now is a good time to have pupils begin collecting pictures of or, better still, bring in common objects which are classes of levers (crowbar, bottle opener, pliers, scissors, shears, see-saw, wheelbarrow, school paper cutter, fishing pool, reel, bat, your arm or leg, etc.). The pupils may keep individual notebooks or bulletin board collections can be made. They may group their pictures or objects by classes of levers if you wish.

On the back of Card 4 is a model for a letter scale which incorporates the concepts of levers and balance. This model is a good "challenge" activity because it not only involves the lever, but it also requires pupils to be able to infer what pieces are needed in order to make the device stable.

The LEGO^{R} manual, page 15, has further suggestions.

CLOSURE

Use Card 4. Looking at the pictures on the front, answer these questions:

1. **What is the name of the simple machine shown in all three photos?** (lever)

2. **What is the term for the bar on which the pipe rests in photo 1?** (fulcrum)

3. **If you moved the fulcrum farther from the box in photo 1, would it be harder or easier to lift?** (harder)

4. **If the handles on the wheelbarrow were longer, would the load be harder or easier to lift?** (easier)

Review the correct answers and the reason for those answers. (The Information Sheet given to the pupils has summaries of basic points.)

Study Master #1

Lesson 2 Record Sheet for the Relationship of Force to Distance

Weight lifted	Force (in paper clips)	Distance (in holes from Fulcrum to end of effort arm)

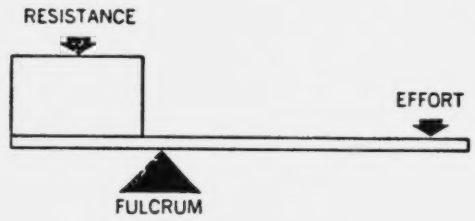
INFORMATION SHEET - LEVERS

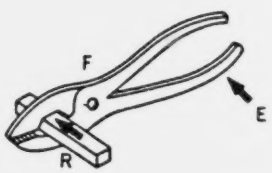
The lever is one of the oldest tools known to mankind. It is a simple machine that enables a person to do things that would otherwise be impossible, such as move heavy loads, loosen tight bolts, and cut or break materials.

The see-saw on the playground is an example of one type of lever. A small person sitting at one end of the see-saw can lift a larger person sitting close to the middle.

The principle of levers is used in almost every hand tool found in a kitchen or workshop. These include such things as pliers, hammers, bottle openers, scissors, wrenches, nut crackers, and ice tongs.

The various levers have been divided into three classes in order to recognize and understand them better.

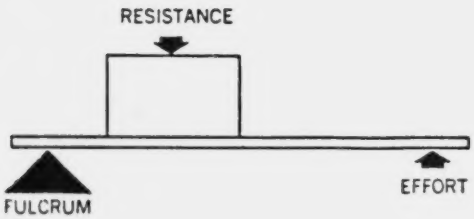


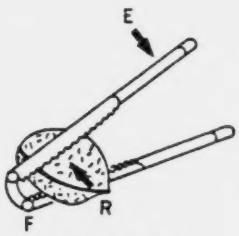


PLIERS

Levers of the First Class

These levers change the direction of forces applied to it and have a pivot point, fulcrum, between the two forces. Examples of levers of the first class include: scissors, pliers, crowbars, and a see-saw.

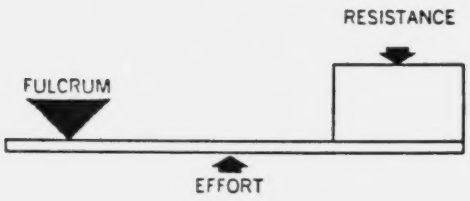


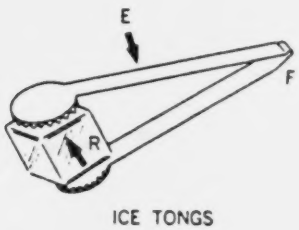


NUTCRACKER

Levers of the Second Class

These levers have the pivot point, fulcrum, at one end and the effort at the other end with the resistance in the middle. Examples include a door on a hinge, a nutcracker, wheelbarrow, oars of a rowboat, and a bottle opener.





ICE TONGS

Levers of the Third Class

Levers of the third class have the pivot point, fulcrum, at one end and the resistance on the other end with the effort in the middle. Examples include tweezers, ice tongs, baseball bat, shovels, and fishing poles.

NOTES

Optional materials needed: Marbles.

GOAL/RATIONALE

The purpose of this lesson is to develop the concept of friction, identify where it commonly occurs, and list its advantages and disadvantages. Most simple machines must deal with friction and also overcome inertia in performing their "work."

Concept Label	Concept Characteristics	Example	Non-Examples
Friction	Friction is the resistance to motion of two moving objects or surfaces that touch. The scientific use of the term friction describes it as a force that opposes motion and turns work into heat energy. The use of lubrication on moving parts of machinery reduces friction and allows them to run more efficiently. Additionally, as in the case of an automobile, some type of cooling system is used to take away the heat being produced by the moving parts. In many cases, friction is necessary, e.g., when walking, you need friction between the soles of your shoes and the pavement; when driving, between the tires and the road, etc.	Rubbing cold hands together to warm them up. When riding your bicycle, if you drag your foot to stop yourself.	The moon orbiting around the earth. An object moving in a vacuum. Your hands placed together without moving them.
Inertia	Inertia is defined as the tendency of matter to remain at rest unless acted upon by a force, or to remain in motion unless acted upon by a force.	When a bus moves forward, a standing passenger falls backwards. When a bus stops, the standing passenger falls forward.	An object acted upon in a "weightless" situation.

ANTICIPATORY SET (Pupil Activity)

Have the students rub their hands together vigorously. Ask them what they feel (heat). Then have them examine the soles of their shoes to see where there are worn areas. Ask: **Do you know that there is a relationship between the heat you feel when rubbing your hands and patterns of wear on your shoe soles?** Follow up that lead question by asking: **What causes shoes to wear out?** (The soles rubbing against the floor.)

Conclude by saying, "As we progress further in this lesson, you will learn more about the scientific connection between these two events."

OBJECTIVES

At the end of this lesson the pupils will:

1. Identify the resistance of movement between two surfaces as friction.

2. Demonstrate or recognize where friction occurs.

3. Identify ways in which friction can be reduced.

4. Identify situations in which friction is valuable.

DIRECT INSTRUCTION

Distribute Card 11. Using the illustrations on the front, ask: **What could you do to increase the speed at which the boy is descending the slide?** If there are no responses forthcoming, suggest that they could oil the surface, spray water on it, have the boy wear slick pants, etc. Tell them that the same force which caused heat when their hands were rubbed together and which must be decreased if the boy is to slide more rapidly is friction. The worn areas on shoe soles are also evidence of friction.

There are many ways to increase or decrease friction. Because friction is the resistance of two surfaces as they move against each other, wear occurs and movement is impeded. Several methods to increase the speed of movement and reduce wear have been devised. The bottom pictures on the front of Card 11 illustrate how friction caused by sliding is lessened by using rollers. Discuss with the pupils the advantages of moving the boxes with rollers (ease, speed, etc.).

GUIDED PRACTICE

To illustrate how rolling lessens friction, have the students push a social studies book across the desk; then place the book on several pencils and push it again. Point out that the pencils are somewhat similar to the rollers used in the pictures on Card 11.

To further reduce friction, place the book on a group of marbles and move it around. Such movement will show them how rolling, e.g., roller bearings or ball bearings, decreases the friction and also increases maneuverability.

Direct the pupils to make the model shown on the inside of Card 11. Have them construct the model through Step 5. Then place the red 54 gram weight crosswise from one blue beam to the other. To move the weight, the pupils must use force (a push or a pull) to move the weight from one end of the model to the other. After they have pushed the weight along, have them again place it at the end of the model. Call attention to the fact the weight does not move unless force is exerted upon it. If the end of the model is raised, however, the weight will slide. Have the pupils measure and record how high the model has to be raised for the weight to slide.

Next have them complete the model as shown in Step 6. (Note that the model is now raised.) Ask the pupils to predict whether the weight will slide more easily now (yes). Have them try sliding the weight again. (The comparison between sliding the weight in Step 5 and Step 6 will not be precise or great, but it is enough to show a difference.)

You can think of the weight moving over the rollers as if a tire were rolling along a road. Only a small portion of the tire is in contact with the weight at any one time. The conveyor is like an "upside down road" surface.

Finally have them place the weight on the rollers as demonstrated in Step 6. They then place the weights on the "conveyor." It should move down easily of its own accord. Have them measure the height of this end of the model and compare it to the height to which they lifted the model for the weight to slide. The difference is a good example of the advantage of rolling or sliding to overcome friction.

INDEPENDENT PRACTICE

Ask the pupils to predict what would happen if the model in Step 6 were raised still higher on the one end. (The weight would move down more quickly). Then have them actually build such a model and test their prediction. (The number of alterations you have the pupils make will depend on your own classroom schedule.)

By building the model on the back of Card 11, the pupils also are investigating other methods of decreasing friction. Have them first try the model as shown. Then ask them to suggest ways to make the weight move more quickly; less quickly. (In addition to changing the placement of the connector peg in the holes, suggest that they also try making the string taut, and then having it slack.)

CLOSURE

Using the last model constructed, ask the pupils to point to and tell you areas where friction occurs (between the string and wheel). Ask them to look at the soles of their shoes. **Why are there worn spots?** (friction-related wear) Before closing, be sure pupils recognize that friction is both harmful, e.g., causes wear on machines, and helpful, e.g., allows tires to grip the road. You will be encountering further examples of helpful and harmful occurrences of friction throughout the unit.

A classroom chart may be started recording occurrences of friction. Whether it is helpful, harmful or some of each can be checked. (Study Master Number 1 may be used here.)

Study Master #1

Observations of Friction: Lesson 3

Occurrence	Helpful	Harmful	Both

Lesson 4 - Inclined Plane, Screw (Part of Card 11)

NOTES

Additional Materials Needed: Paper, sheet metal screws and nails of the same diameter, small bars of soap, various screws supplied by pupils. Teacher Demonstration Materials: axe, knife, saw, bolt, or wedges for splitting logs.

RATIONALE/GOAL

The purpose of this lesson is to describe inclined planes, including screws, and to show how these simple machines make work easier.

Concept Label	Concept Characteristics	Examples	Non-Examples
Inclined plane	An inclined plane is a simple machine. It can be defined as a slanted surface used to raise objects. Using an inclined plane to lift an object, the object is moved a longer distance, but less force is needed. Work is made easier. Another form of an inclined plane is a wedge.	Ramp Stairs Axe blade	Bicycle wheel Block and tackle
Screw	A screw is a simple machine. In effect, it is an inclined plane wrapped around a core. The distance between the threads and the screw is called the pitch. As the screw is turned, the threads move slowly into the object.	Screw clamp Scaffold jack Scissor jack Bolts Wood screws Sheet metal screws	Block and tackle Axe blade Bicycle wheel Nail

You may wish to require pupils to bring in small bars of soap now so that they have them available for the Guided Practice section later in this unit. Also ask each to bring at least two screws of different sizes. Sheet metal screws are preferable to wood screws because wood screws taper which adds another variable not addressed in the investigations done in this lesson.

ANTICIPATORY SET (Teacher Demonstration)

Display a piece of paper, a knife, and a screw. Ask the pupils if they know what these three objects have in common. Accept any reasonable suggestions. Tell them that at the end of the lesson they will have the answer - at least so far as this unit is concerned.

OBJECTIVES

At the end of this lesson, the pupils will:

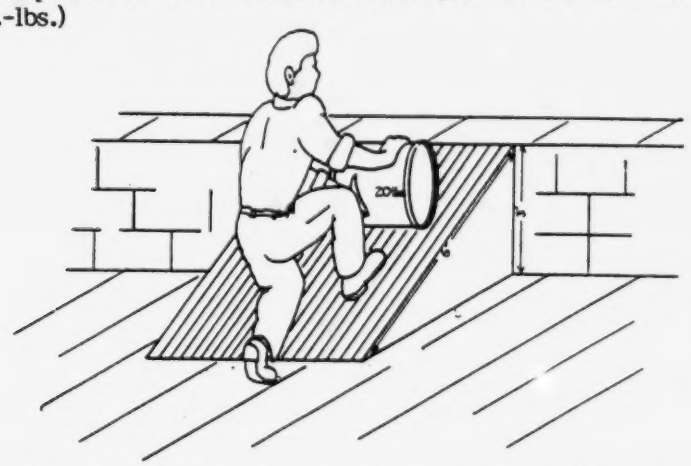
1. Identify an inclined plane as a sloping surface which makes work easier.
2. Demonstrate how an inclined plane makes work easier. (W = F x D)
3. Recognize that a wedge is a double inclined plane.
4. Understand that a screw is an inclined plane wrapped around a core.

DIRECT INSTRUCTION (A)

Refer pupils to the top photo of Card 11. Tell them that this slide is an example of a simple machine called an **inclined plane.** An inclined plane is simply a sloping surface, but unlike the lever, the inclined plane does not move in order to do work.

GUIDED PRACTICE

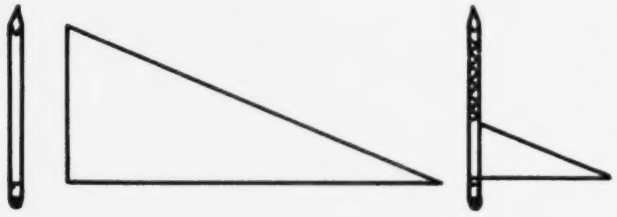
Refer the pupils to the model they had built in Lesson 3 through Step 5 of Card 11. Although the focus originally was on the friction involved in moving the weight across the beams, the pupils should be able to identify the construction as an inclined plane. Ask them to suggest ways in which the inclined plane makes work easier. Remind them of the scientific definition of work, i.e. W = F x D. Therefore, if one is to lift a 20 pound box to a truck bed 3 feet above the ground, 60 foot-pounds of work would be done. (20 lbs. x 3 ft. = 60 ft.-lbs.)



Remind the pupils that as distance increases, the force needed to do the same amount of work will be less. Ask: **If a ramp five feet long were used, how much force would be required to do the same amount of work?** (60 = F x 5 or F = 12 pounds). **If a ten foot ramp were used?** (60 = F x 10 or F = 6 pounds.) Ask: **How could the ramp of Step 5 on Card 11 be improved to make work easier?** (It could be made longer.) Have them demonstrate their understanding by building a lengthened model.

DIRECT INSTRUCTION (B)

Have the pupils make a triangular piece of paper on which they have colored the hypotenuse edge.



First, identify this sheet as an inclined plane when it is held on edge with the base down. Have them lay a pencil against the base and roll the pencil up in it. When finished, they can see that the colored edge strongly resembles the pitch, the metal thread, of a screw. If possible, give at least each pair of students an actual sheet metal screw. Point out to them the pitch as described above.

GUIDED PRACTICE

Give each pair of students a nail and sheet metal screw of the same diameter and a piece of soap. (They should have brought in their own bars of soap). Have them push the nail into the bar of soap noting the amount of force needed. Using a screw of the same diameter, have them twist it into the soap. (They can do this by hand; no screwdriver is needed). They should note that the screw moves into the soap more easily than the nail. Elicit from them that the thread, which is really an inclined plane around the screw's core, acts like a small knife, or wedge, which cuts into the surface.

Because most common wedges are sharp edged tools, you may find it advisable to simply display an axe, a knife, and a saw. You can demonstrate for the class how these wedges work. Point out that a wedge is a double inclined plane. If you have an axe available, it is appropriate at this time to point out the relationship between the width of the axe head and the length of its blade as a factor in determining how easily the work will be done. The longer the blade compared to the width of the head, the easier the work will be. Or if you have available wedges used for splitting wood, you can use these to show the relationship of the head width

and blade length to the ease with which the wedge can be pounded into the wood. In both cases, the length of the sides are analogous to the length of the inclined plane.

INDEPENDENT PRACTICE

To demonstrate how the pitch and size affect the ease with which the screw moves, have the pupil twist the screws (which they have brought in) into their bars of soap. (At this point, you are not focusing on mechanical advantage, but rather simply on differences the pupils can feel as they twist in screws of various sizes.) They may wish to record in their notebooks the relative ease for various size screws. They may measure or identify the screws according to the length of the screw or some other common factor that they can observe which will differentiate one screw from another.

This can be a homework assignment. Be sure the pupils have an opportunity to share their notebook entries with others. They should be asked to explain the reasons for placing objects in the various categories.

Have the pupils either draw or paste in their notebooks illustrations of commonly used inclined planes, (ramps, stairs, slides, roller coasters, winding mountain roads, etc.) and screws (bolts, auto jacks, meat grinders, etc.). As a subset of the inclined plane, they may make the same kind of notebook entries for wedges, (knives, axes, blades of scissors, saws, doorstop, nails, straight pins, etc.).

CLOSURE

From the objects you have in the classroom, ask the students to record on paper whether the object shown is a screw or an inclined plane.

Show a:

1. Picture of a ramp, or refer to the stairs in your school if you have them. (inclined plane)

2. Bolt, or refer to the inside of the school pencil sharpener. (screw)

3. Knife. (inclined plane or wedge)

At the close, review with the pupils the reason why each object falls into the category named. They should recognize that stairs are cuts made into an inclined plane; the bolt has an inclined plane wrapped around a core just as does a screw; and the knife has two sides which are really inclined planes back-to-back.

Lesson 5: Wheel and Axle
(Part of Card 5)

The purpose of this lesson is to introduce the pupils to the wheel and axle and to investigate the way it affects the work done.

Concept Label	Concept Characteristics	Examples	Non-Examples
Wheel and axle	A wheel and axle is a simple machine. The wheel has a larger radius than the axle. They act like a lever with the center of the axle being the fulcrum. As a result, a small effort force can be used to move a larger resistance force, thus making work easier.	Bicycle wheel Crank	Stairs Axe blade Ramp

NOTES

Have students bring in at least one jar lid or a circular object to trace.

Materials Needed: Paper, pupil-supplied objects to trace, plastic lids of different sizes, crayon /marker per pupil, scissors, screwdriver.

ANTICIPATORY SET

Give each pupil a piece of paper and have them trace around a circular object such as a jar lid. Cut out the drawing. (If your pupils have compasses available, they can use these.) Mark the center of the circle and poke a pencil through it at this point. Use the pencil as the center of the "top." Make a colored mark on the outside rim of the circle and a mark on the pencil opposite the rim mark. Tell them, "You have just made another simple machine."

OBJECTIVES

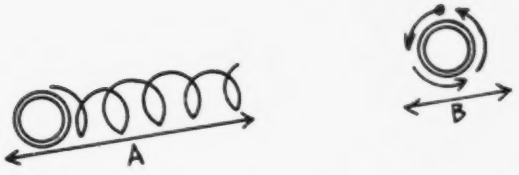
At the end of this lesson, the pupils will:

1. Recognize the wheel and axle as a circular disk and center post which are connected and function together.
2. Demonstrate that the wheel and axle can multiply speed, distance, and force.
3. Recognize that the wheel and axle cannot multiply speed and force at the same time.
4. Identify everyday examples of the wheel and axle.

DIRECT INSTRUCTION (A)

Tell the pupils that the "top" is really an example of a **wheel and axle.** Have them spin the top and note that the mark on the rim moves faster than the mark on the pencil. Make this analogy: If a person were on the rim of the wheel, s/he would have to run faster to stay opposite a person simply turning around as the axle does. This is similar to what happens when playing "Crack the Whip." The outside persons must run rapidly to keep up with a center person who walks.

Use a circular object such as a jar lid or plastic lid. Make a mark on the rim. Begin with that mark down as the starting point. Put a mark on the overhead. Roll the lid on its rim one complete revolution. Mark on the overhead where you stop. Point out that this is the distance traveled by the "mark" in one revolution. (Alternate procedure: Cut strips of paper to wrap around the circumference of the "lid." Lay the paper out in a straight line to show the distance the wheel would move in one revolution.) If you use a plastic lid as the demonstration circle, you can poke a nail or tack through the center as the axle. Put this device on the overhead. As you "spin the axle" once, point out that the outer rim has traveled the measured distance.



Explain that the lid with the nail or tack is a wheel and axle. In a wheel and axle, the two components are joined and turn together.

Have the pupils follow the above procedure with the lids they have brought in to show the varying distances which different sized lids travel. Let them compare their measurements with each other. Be sure they recognize that the larger the wheel, the greater will be the distance traveled.

Return to the original "top" wheel and axle. Have them spin the top, noting that the original mark they made must travel a greater distance than the small axle.

Relate the greater distance the wheel travels to the greater speed coming from a wheel and axle when force is put on the axle.

These trials reinforce that one of the things the wheel and axle can do is to multiply speed and multiply distance. (Because the wheel is fastened to the axle, as the axle travels a short distance, the outer rim of the wheel must travel faster to cover the same distance.)

INDEPENDENT PRACTICE

Ask the pupils to use components of the LEGO^{R} kit to construct a wheel and axle. For those who need specific assistance, you may refer them to the inside pages of Card 5, through Step 4. These illustrations should provide enough guidance to ensure success.

Once the model is built, ask each group to demonstrate briefly their wheel and axle. The pupils should be able to:

1. Identify the two major parts, and

2. Show how to increase speed and distance in the wheel portion. To show the increased speed, be sure the effort is applied at axle.

If possible, keep this model intact.

DIRECT INSTRUCTION (B)

Review with the pupils the trial spins they did with their tops. Then call attention to the doorknob of your classroom door. Tell them that this doorknob is also a wheel and axle; however, it does not increase speed. As with many wheels and axles, the doorknob multiplies force. Ask: **Which part of the doorknob is the wheel?** (the knob). Elicit from them that the axle has to be inside the door where it isn't seen.

Refer to the classroom pencil sharpener. (Previously they have studied the wedge and should recall that the inside part which sharpens the pencil is made of a wedge or screw.) Ask: **Where do the wheel and axle occur in this machine?** Point out that the handle is the wheel and the inside bar is the axle.

Take off the outside cover so that they can see the inside of the sharpener easily. Have them note that as the wheel (knob of handle) is turned one revolution, it has traveled a wider circle than the axle, the inside slot in which the pencil fits.

Elicit from them that if the handle were removed from the pencil sharpener, you would need a great deal more effort in order to turn the axle directly with your fingers. You may let some pupils try turning the axle with their fingers. Therefore, by using the handle, and thus moving the wheel a greater distance, you are increasing the force given off by the axle. Thus, a wheel and axle can multiply force. However, it cannot multiply both force and speed at the same time.

GUIDED PRACTICE

Do not allow them to hold the axle in this activity with anything other than their fingers. This will reduce the chance of equipment breakage.

To demonstrate how force is multiplied when force is placed on the wheel of a wheel and axle, have a person of each team hold an "8" axle tightly. The other person tries to turn the axle using just his/her fingers. Put the "steering wheel" on the end of the axle. Again, have the person try turning the axle while the partner holds the axle tightly. They will discover that now the axle can be turned. Let the partners switch roles so that both members can experience the multiplication of force which occurs when effort is placed on the wheel portion of the wheel and axle.

INDEPENDENT PRACTICE

Have the pupils use the model of the wheel and axle they built previously (Part A). Ask them to alter the model so that they now demonstrate how to achieve an increased force. (The effort must be applied to the wheel.)

Ask the pupils to suggest ways that more force could be derived. (One possibility is to use a larger wheel.) They may wish to alter their models to do this. (The parts available in the kit may limit alteration, but you can suggest that they do not have to use only kit components.)

Have them begin a collection of pictures or objects which are everyday examples of wheels and axles. (Car steering wheel, screwdriver, unicycle, etc.)

CLOSURE

Use the following questions to summarize this lesson. Be sure to review the correct answer at the end of the questioning.

Refer to the classroom doorknob.

1. Ask the pupils to **write on paper the name of this simple machine.** (Wheel and axle)

2. **Which part is the wheel?** (The knob)

3. **Which part is the axle?** (The bar inside the door)

4. **Does the doorknob multiply speed or multiply force?** (Multiplies force)

Then show the pupils a screwdriver. Ask them:

1. **How can this tool be a wheel and axle?** Elicit from them that their hand becomes the wheel as it grips the handle of the screwdriver.

2. **Where is the axle?** (The shaft which fits onto the top of the screw.)

3. **Does the screwdriver increase speed or increase force?** (Increases force)

Again, review with the pupils the correct responses to these questions. Have them record this summary statement in their notebooks before proceeding to the next lesson: "When using a wheel and axle to increase speed and distance, place the effort on the axle. To increase the force given off, place the effort on the wheel."

Lesson 6 - Belt Transmission: Multiplying Force, Multiplying Speed (Card 5)

NOTES

GOAL/RATIONALE

The purpose of this lesson is to show how wheels and axles connected by belts can be used to transfer force and can either multiply force or multiply speed depending upon where the effort is placed.

Concept Label	Concept Characteristics	Examples	Non-Examples
Belt transmission	The term "belt transmission" refers to the transfer of force or speed by the use of wheels and axles connected by a belt(s). Either force or speed can be multiplied, depending on where the effort is placed.	Wood lathe Sewing machine Clothes dryer Vacuum cleaner Fan belt on automobiles	Gears in an automobile

ANTICIPATORY SET

Have the pupils study the pictures on the front of Card 5. Elicit from them that these are close-ups of belts used in (1) a piece of large farm machinery, (2) a wood lathe, and (3) a sewing machine. Ask: **"What simple machine is the basis for these compound machines?"** (wheel and axle)

OBJECTIVES

At the end of this lesson, the pupils will:

1. Describe pulley systems in which both pulleys turn in the same direction.
2. Describe pulley systems in which the pulleys turn in opposite directions.
3. Describe pulley systems in which speed is multiplied.
4. Describe pulley systems in which force is multiplied.

5. Describe the slippage that occurs when belts are used.

6. Recognize that belt transmission is a common method of transferring power.

DIRECT INSTRUCTION

Have the pupils build the model shown on the inside of Card 5, through Step 5. At the end of Step 5, have the pupils put a connector peg in each pulley wheel so that the pegs are exactly opposite each other.

There is a study master which can be used here as well as in the closure.

To begin the investigation, identify the large steering wheel as the **drive wheel**. The drive wheel is the wheel on which the effort is placed. Ask:

1. **Will the wheels turn in the same direction or opposite direction?** (opposite) Turn the drive wheel a few times to verify the direction.

2. **The two wheels are the same size. Will they turn the same number of times?** (No)

This may be a convenient place to review where friction occurs, i.e., between the pulley wheels and the belt.

Page 19 of the LEGO^{R} Teacher's guide has specific data on slippage.

3. **Did the pegs end exactly opposite each other?"** (No)

   Tell the pupils that the lack of direct correlation in the turning ratio between the two pulley wheels is called slippage. Slippage is a factor in all belt transmission.

   Be sure the connector pegs are exactly opposite each other to start. Turn the drive wheel 12 times.

GUIDED PRACTICE

Have the student cross the belt as shown in Inset 1. **Will there be slippage?** (Yes)

Will there be as much slippage? (No)

Another way to show the differing amounts of slippage is to have one pupil count the number of revolutions of the second wheel while his/her partner turns the drive wheel exactly 12 times. For the open-belt transmission, the ratio comes out fairly consistently as 11:12. For the crossed-belt tranmission the ratio is less precise, e.g., about 11¼:12. Some pupils may accept a challenge of calculating more precise ratios.

To verify that slippage is reduced when the belt is crossed, again have the pupils turn the drive wheel 12 times. Note the position of the two pegs when done. (There should be less difference compared to Trial 1 above.)

Discuss with the pupils where friction occurs in the crossed belts. They should note that there is more contact between the belt and the two wheels; therefore, this contact is a factor in reducing the amount of slippage.

Next have the pupils alter their models to look like the one on Inset 2.

Are the two wheels connecting the belts still the same size? (No)

Which is smaller, the drive wheel or the driven wheel? (The drive wheel. Notice the gray bushing is directly driven by the steering wheel on the back of the model.)

Based on previous work with the wheel and axle, have the pupils predict which wheel will turn slower. (The driven wheel/pulley wheel.) Then have them verify their predictions. (If a connector peg is placed in one of the holes of the driven wheel, the rate of turning is more easily seen.)

Does this model multiply force or speed? (force) The pupils must understand that the driven wheel is the output. Therefore, since the larger wheel is the output wheel in this model, force is achieved.

At this point, you may find it helpful to have the pupils record what they have discovered through their trials to date.

The pupils should also alter the model as shown in Inset 3. Lead them through the same analyzing process as you did with Inset 2. Summarize by having the pupils note that in this model, the driven wheel is smaller and therefore the output will be speed.

INDEPENDENT PRACTICE

Have the pupils study the two models on the back of Card 5. Encourage them to predict which wheels will turn at the same speeds and which will rotate at different speeds. (The pistons are placed on the ends of the axles to make it easier to study the rate of rotation.) If they observe carefully, they will note that in the top model, only one belt is used.

Have them first let the belt go around the outer edge of both small wheels. Note the slippage. Then have them place the belt around the bushing as shown. Ask them why there is now less slippage. (There is a greater contact area and therefore more friction.)

Be sure they note that the bottom model has two belts connected to the same drive wheel but in different ways. If they refer again to pictures 1 and 2 on the front of Card 5, they can see everyday uses of this type of belt transmission, i.e., from one power source several rates of rotation can be achieved.

Have the pupils list the advantages and disadvantages of belt transmission. (Example: Belts are quieter and

less expensive to replace. Because of slippage, they are not satisfactory where precision is needed.)

"Information Sheet - Belt Transmission" is a summary of facts about belt transmissions. Pupils should be given copies at this time.

CLOSURE

Because their models are no longer intact, you can refer again to the pictures on the inside of Card 5. Have the pupils respond in writing to these brief questions. By having all pupils respond, you engage their active participation in the review.

1. Look at the drawing for Step 5. **In which direction will the wheels turn, the same or opposite?** (Same)

2. Look at Inset 1. **In which direction will the wheels turn?** (Opposite)

3. **Will the driven wheel in Inset 2 give out force or speed?** (Force)

4. **Will the driven wheel in Inset 3's design give out force or speed?** (Speed)

5. **Why do wheels of the same size connected by belts not rotate exactly the same number of times?** (slippage)

6. **Will a clock run by belts be accurate?** Explain. (No, belts permit slippage; therefore, the timing would not be precise.)

Review with the pupils the correct answers and the reasons for those correct answers. Have them record these summary statements in their notes:

1. Wheels connected by an open belt turn in the same direction.

2. Wheels connected by a crossed belt turn in opposite directions.

3. When a larger drive wheel turns a smaller wheel, speed results.

4. When a smaller drive wheel turns a larger wheel, force results.

5. All belt transmissions have slippage.

ALTERNATE CLOSURE

Use Lesson 6 Study Master #1 to make an overhead transparency. Based on that transparency, have the pupils respond to these questions:

1. **In which model(s) do the wheels turn in the same direction?** (A, C, D)

2. **In which model(s) do the wheels turn in opposite directions?** (B)

3. **In which model will the driven wheel give force?** (C)

4. **In which model will the driven wheel give speed?** (D)

5. **In which model(s) does slippage occur(s)?** (A, B, C, D)

6. **Would a belt-driven clock be accurate?** (Explain) (No. Slippage occurs and therefore the precision needed for clocks is not possible.)

Follow the review and summarizing procedure above.

LESSON 6, INFORMATION SHEET
"BELT TRANSMISSION"

One of the most common ways of transmitting (transferring from one place to another) movement from one machine to another is by the use of a belt or a chain. Most machines driven by an electric motor are equipped with a belt. The reasons for this include:

1. If the shaft breaks or becomes blocked, the belt can slip and prevent further damage;
2. The belt is usually fairly quiet when it is operating;
3. A belt can easily and economically be replaced.

Belts are used in many machines such as clothes dryers, sewing machines, and vacuum cleaners. They are also used in automobiles to run the alternator, water pump, fan, power steering unit, and air conditioning unit.

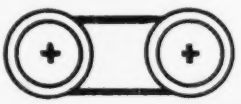
There are many different kinds of belts, the most common is the "V" belt. It is called a "V" belt because of its shape, and it fits in a special pulley. This shape gives it a greater contact surface area and greater strength. The greater contact surface area reduces the amount of slip.

Flat belts are quite common in vacuum cleaners and in clothes dryers.

Another way of transmitting movement from one shaft to another is by the use of a chain. Common applications include bicycles, motorcycles, and riding lawnmowers. Chains are used when slipping is not desired. The chain often fits over sprocket wheels; however, the chain sprocket wheel assembly is more costly, requires constant lubrication, and is noisier.

As you worked with belt transmission in this lesson, you noticed that the two wheels did not turn exactly the same amount. This is especially noticeable if you turn the wheel ten or more revolutions and count the number of revolutions on the outer wheel. This difference is due to slippage.

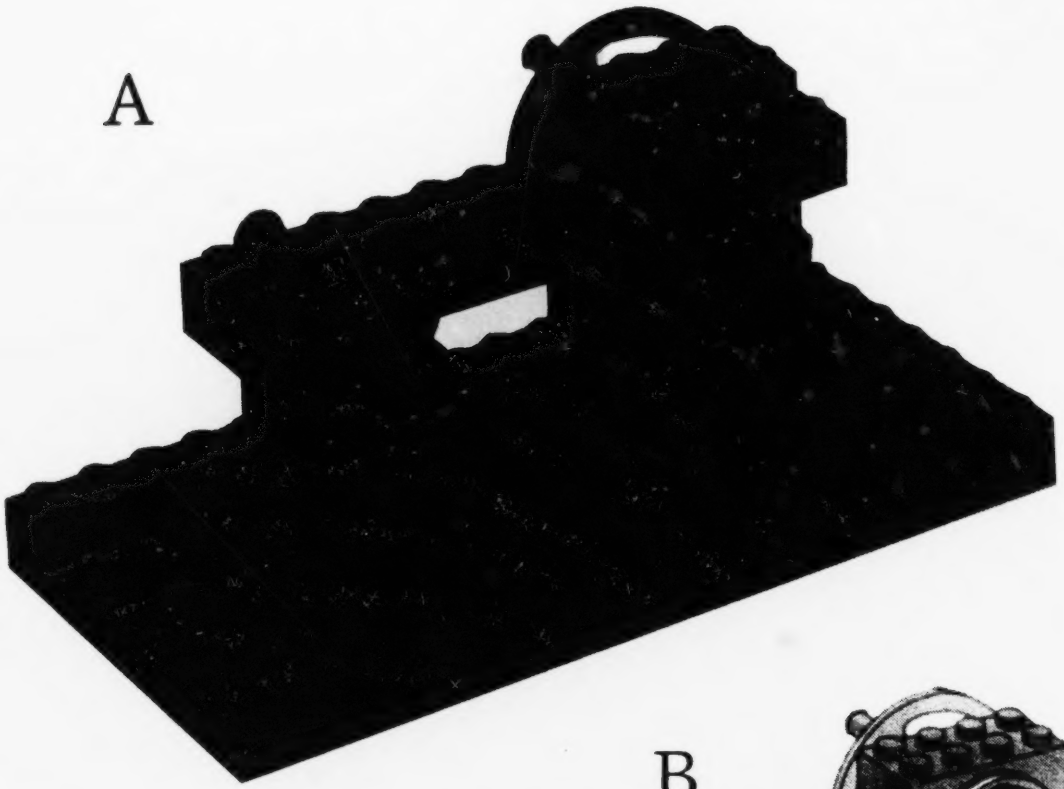
Open Belt Drive



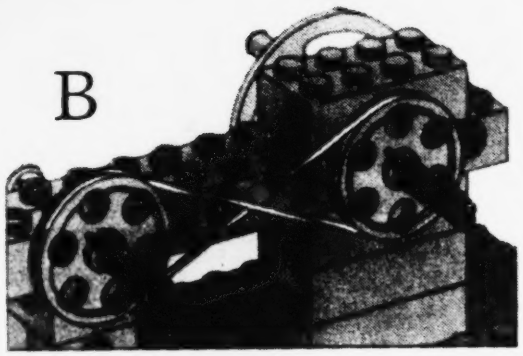
Crossed Belt Drive

STUDY MASTER NO. 1 LESSON 6, "BELT TRANSMISSION"

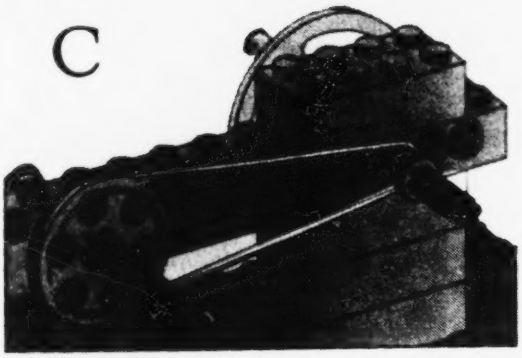
A



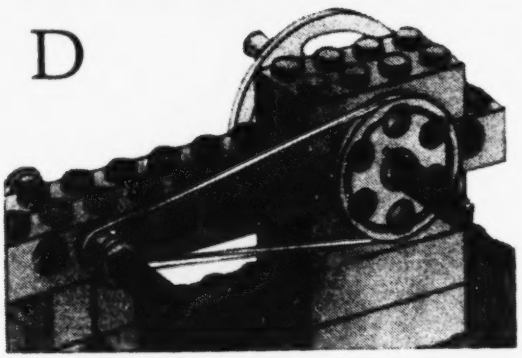
B



C



D



Lesson 7 - Gears and Gear Ratio (Cards 6, 12, 7)

NOTES

Optional Materials Needed: Hand egg beater, hand-wound alarm clock.

GOAL/RATIONALE

The purpose of this lesson is to demonstrate the transmission of power using gears.

Concept Label	Concept Characteristics	Examples	Non-Examples
Gear(s)	A gear is a simple machine. It is a toothed-wheel which precisely meshes with another toothed-wheel. Two or more gears are used to transfer force, transfer speed, or change direction.	Bevel gears Spur gears Crown gear (wheel) Rack-and-pinion gear	Block and tackle Inclined plane Screw

ANTICIPATORY SET

Make a transparency of Lesson 7 Study Master #1. Ask the pupils if they can suggest places where they could see items such as these. You may also tell them to imagine that these pictures have been enlarged or have been miniaturized from the real object. Continue to brainstorm locations for a few minutes.

OBJECTIVES

At the end of this lesson, the pupils will:

1. Describe a gear as a toothed-wheel which precisely meshes with another toothed-wheel to transfer force.
2. Recognize that gears are directly related to wheels and axles.
3. Make a model which will gear-up, or increase speed.
4. Make a model which will gear-down, or increase force.

5. Arrange gears so that the driven gear(s) and the drive gear turn in the same direction.

6. Arrange gears so that the driven gear(s) and the drive gear turn in opposite directions.

7. Recognize that gears overcome the slippage problem of belt transmissions.

8. Recognize that the exact turning ratio of one gear to another can be determined if the number of teeth on each gear is known.

9. Make a model which will transfer force at an angle.

DIRECT INSTRUCTION (A)

Using a transparency from Study Master #1, ask the pupils if they know the name for these objects. Most will probably say gears immediately; if not, tell them. Tell them that **gears** eliminate the slippage factor in belt transmission because to work properly they must mesh, fit into each other, exactly.

You may wish to borrow gears from the second grade Systems and Interaction kit to use on the overhead.

Then have them look at the photographs on the front of Card 6. Photos 1 and 2 show close ups of how the gears mesh; Photo 2 is a close up of part of the winch in Photo 3.

GUIDED PRACTICE

Before starting GUIDED PRACTICE, you may wish to review the proper labels for the pieces they will need to use, e.g., 40-toothed gear, bevel gear, crown wheel, etc. (Otherwise you may get references to "little gray pieces" and there are many, "little gray pieces.")

Segment I

Before having the pupils build the white model shown on the inside of Card 6, ask them to predict which way the gears on the white model and which way the gears on the yellow model will turn. Then have them build both models to verify their predictions. (Some pupils will intuitively realize that gears which directly mesh will turn in opposite directions; others may assume they will turn as do the two wheels connected by an open belt. Therefore, they need to experience the difference.)

The Guided Practice section may be broken into three parts at each segment.

Note that in these models, they are dealing only with the direction of the gear movement. To show the difference between belts and gears, have them attach a connector peg to the driven gear. Then using the steering wheel, turn the drive gear several times. The pupils will see that the gears turn the exact same number of times. Even when a smaller eight-toothed gear is inserted between the two large gears, the driven gear and the drive gear turn the same number of times.

Segment II

To more specifically address the question of speed, or the ratio of turns of one gear compared to another, have the pupils watch the small eight-toothed gear as they turn the drive gear. They can easily see that it turns much more rapidly.

To pursue further the concept of gearing up for speed or gearing down for force, have the pupils look at the photos on Card 12. Ask: **How many times does the minute hand rotate compared to the hour hand? ... the second hand to the minute hand? ... the second hand to the hour hand?** (12) **What inferences can you make about the number of axles needed to accomplish this?** (There need to be three different shafts or axles with three precise rotational speeds for seconds, minutes, and hours.)

Photos 3 and 4 are closeups of automobile transmissions showing complicated arrangements of different sized gears.

Have the pupils build the white model on the inside of Card 12. They should be aware that the drive gear has 40 teeth compared to only eight for the small driven gear. Ask them to predict the number of turns the driven 40-toothed gear will have. Have them write their predictions on paper and test them by using the model.

Many students may assume because both the driven and drive gears have 40 teeth, they will turn the same number of times as they did on Card 6. However, note that this time the driven 40-toothed gear is connected to an eight-toothed gear which is turning five times for every turn of the drive gear. Therefore the driven gear will turn five times. Study Master #2 can be used to aid in your explanation.

Also have them predict the number of turns for the second eight-toothed gear on driven axle 2. (25) The easy way to check this ratio is to switch the drive gear on to the small eight-toothed gear as shown in the yellow model. They will find that they will have to turn the steering wheel 25 times to get the 40-toothed gear on the other end to turn once.

Segment III

Before building the red model, ask the pupils to predict whether the turning ratio will be the same as on the yellow model (no). (They should see that a 24-toothed gear has been substituted for the 40-toothed gear.) Ask them to try to figure out the ratio and then check their predictions as done previously. (The ratio is 15:1. The 40-toothed gear will turn the eight toothed gear five times; this in turn makes the 24-toothed gear turn three times, which will make the second eight-toothed gear rotate 15 times.) Again, they can check this by changing the second eight-toothed gear to the drive gear and counting the number of times it must be turned to get the 40-toothed gear to turn once.

CLOSURE

The pupils may respond to these questions by using thumbs up for "yes or agree," thumbs down for "no or disagree," thumbs sideways for "I don't know." By having pupils respond, you engage their participation in the review. Have them copy each statement in their notebook as you conclude the question.

1. Gears which mesh will turn in opposite directions. (yes)

2. A small gear connected to a large drive gear will turn faster than the large drive gear. (yes)

3. Gears in good condition do not have slippage. (yes)

4. You can determine the turning ratio of one gear to another by counting the teeth of each gear. (yes)

5. If the drive gear is smaller than the driven gear, you will get an increase in force. (yes)

DIRECT INSTRUCTION (B)

If you have an egg beater, pupils can observe it carefully, noting how gears are set at angles. Use the photos on Card 7 and point out the bevel gears, which are easily seen in Photos 2, 3, and 4.

GUIDED PRACTICE

Have the pupils construct the white model and experience turning the drive wheel. They should note that the two beveled gears mesh and turn at the same rate.

Have the yellow model built. Ask them to count the number of teeth on the crown gear (24) and on the small gear (8). Have them predict the number of turns the small gear will make when the crown wheel turns once (3). Have them verify their predictions. Be sure the pupils understand that two things are involved in this model's transmission: a change of direction and an increase in speed.

INDEPENDENT PRACTICE

Have the pupils build the model on the back of Card 7, the drill.

For your information: to keep the eight-toothed gear, which holds or looks like the drill bit, in place, the pupils need a 1 X 2 beam in between the two shafts. The other construction pieces can be seen by looking carefully at the model.

Fastening a piston to the bottom of the drill makes counting the resolutions easier.

Once the model is complete, have the students change the handle from the placement shown on the picture to the other shaft. Before trying the model, have them predict whether this change will affect the rate of turning. For those who think there will be a difference, ask them to predict in what way. (When the second shaft becomes a drive shaft, the drill turns more slowly. The original ratio is 9:1; the ratio now becomes 3:1.)

Depending on your class time, you may have the pupils build the models on the backs of Cards 6 and 12 (Card 6 has a gear train, multiple linear connection of gears; the model on Card 12 results in a ratio of 75:1.)

CLOSURE

Use whole-class response techniques as in the closure for Part A. Have them copy the statements in their notebooks.

1. Power from gears can be transmitted at angles. (yes)

2. Beveled gears can be used to transmit power at angles. (yes)

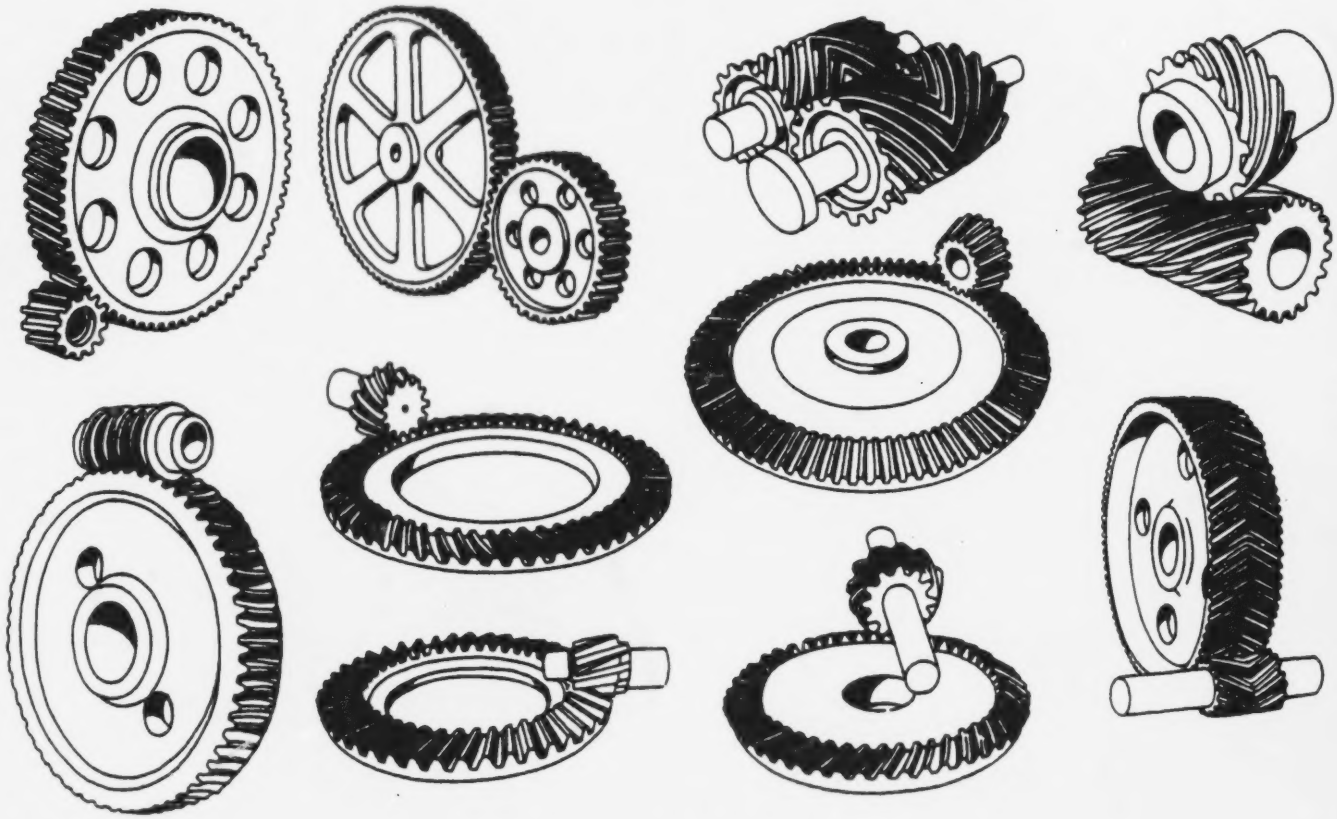
3. Angular transmission can be done in ratios as with straight line transmission. (yes)

(If you wish, you can repeat the questions from Part A.) Study Master #3 may be given to the pupils at this time.

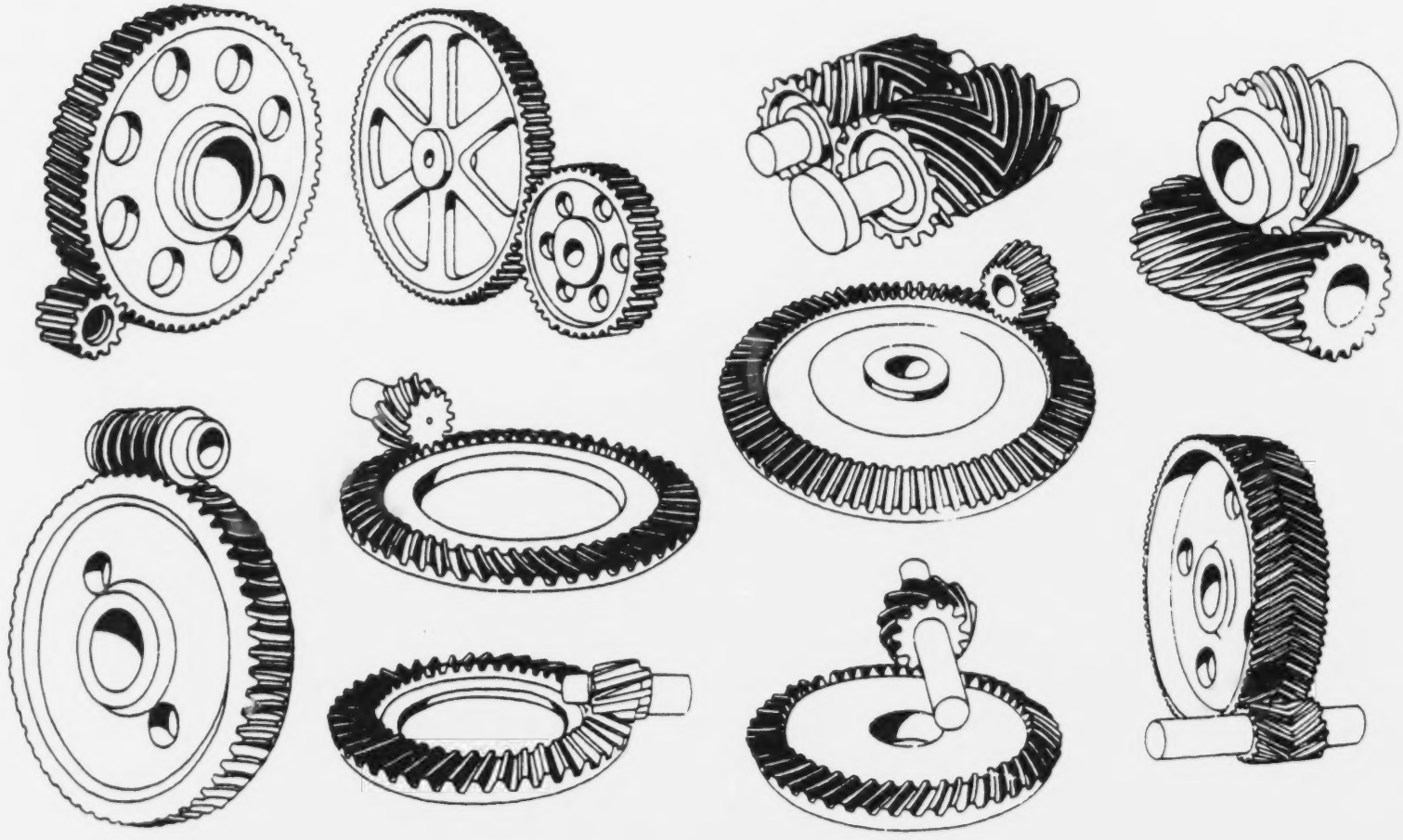
LESSON 7, STUDY MASTER NO. 1
GEARS

The gear wheel is used when a high gear ratio is required in a limited space, when a very large torque is to be transmitted, or when two or more shafts are to rotate with an accurate transmission ratio. The phenomenon of slip, makes belt transmission unsuitable for use in these cases.

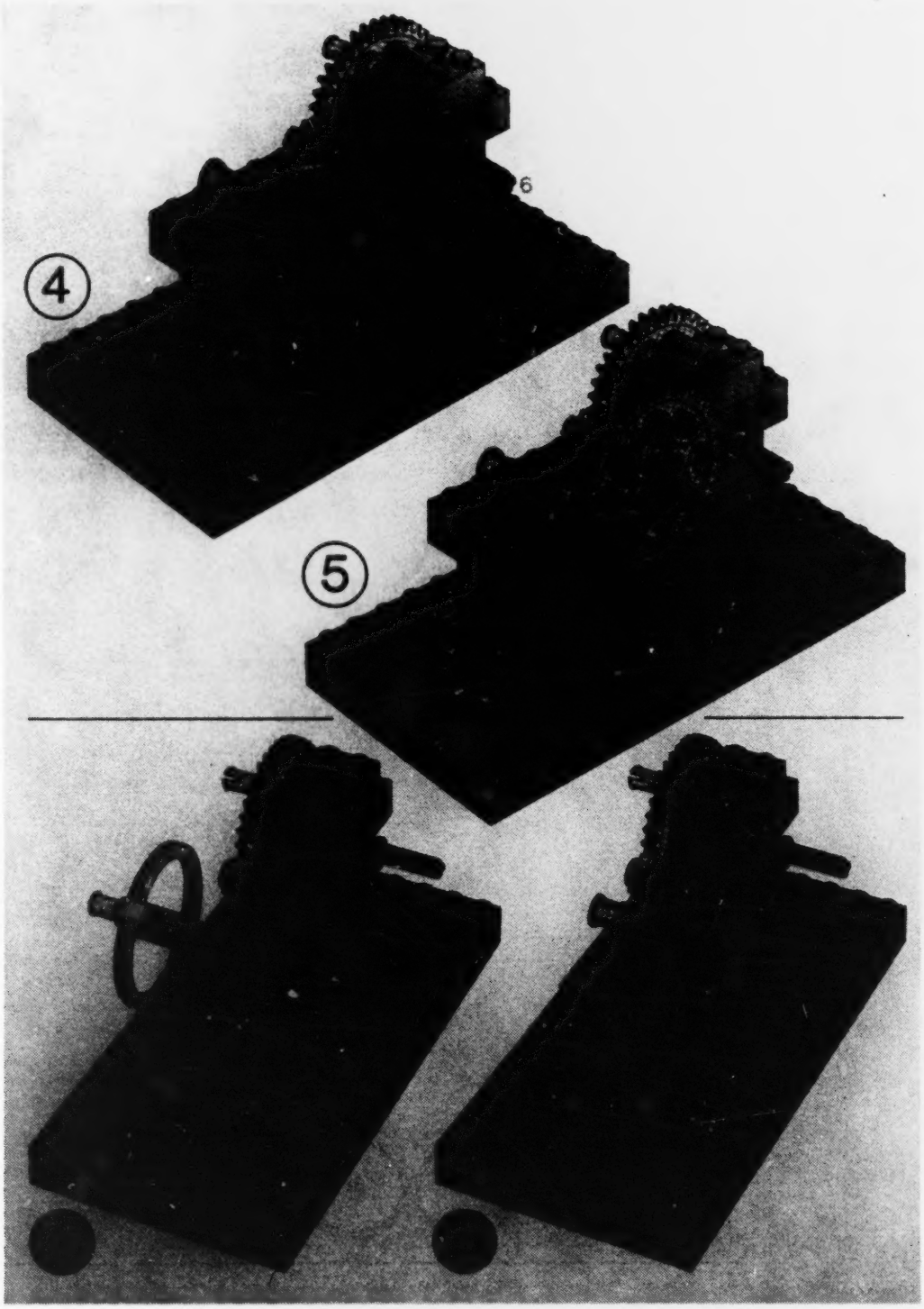
Gear wheel teeth can vary greatly in size, number, and appearance.



STUDY MASTER NO. 1 LESSON 7



STUDY MASTER NO. 2, LESSON 7, "GEARS"

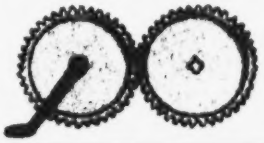


STUDY MASTER NO. 3,

LESSON 7

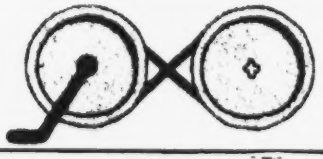
When you are using gears or pulleys to transmit movement, these are the rules:

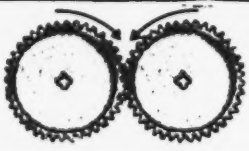
1. Wheels the same size = input speed the same as output speed.
2. Input wheel smaller that output wheel = input speed greater than output speed.
3. Input wheel larger than output wheel = input speed less than output speed.
4. Crossing the belt reverses the pulleys.
5. Pairs of gears turn in opposite directions. When the drive gear slows down the output, it increases the turning force and vice versa.

1. 

2.

3.

4. 

5. 

Teacher Information Relating Universal Joints to the Mechanics of a Car

The system used to transmit power from the engine of the car to the driving wheels includes the following parts: manual or automatic transmission system, a driveshaft, universal joints, differential, and axles. The manual transmission contains sets of gears. These gears are used to increase the twisting power or torque of the engine. The transmission allows the car to operate at different speeds, move easily from a stop, or back up. See figure 1.

The differential is another set of gears that changes the direction of the power from the engine out to the wheels. See figure 2.

The driveshaft connects the transmission to the differential. The driveshaft on a front engine, rear drive car, is a long piece of pipe. The transmission and the engine are attached to the frame of the front of the car. The differential is attached to the rear wheels of the car. The wheels move up and down as the car goes over bumps so the driveshaft must be flexible. At each end of the driveshaft is a universal joint. Two or three universal joints are used on most long driveshafts. See figure 1.

Figure 1 Inside View of a Manual Transmission

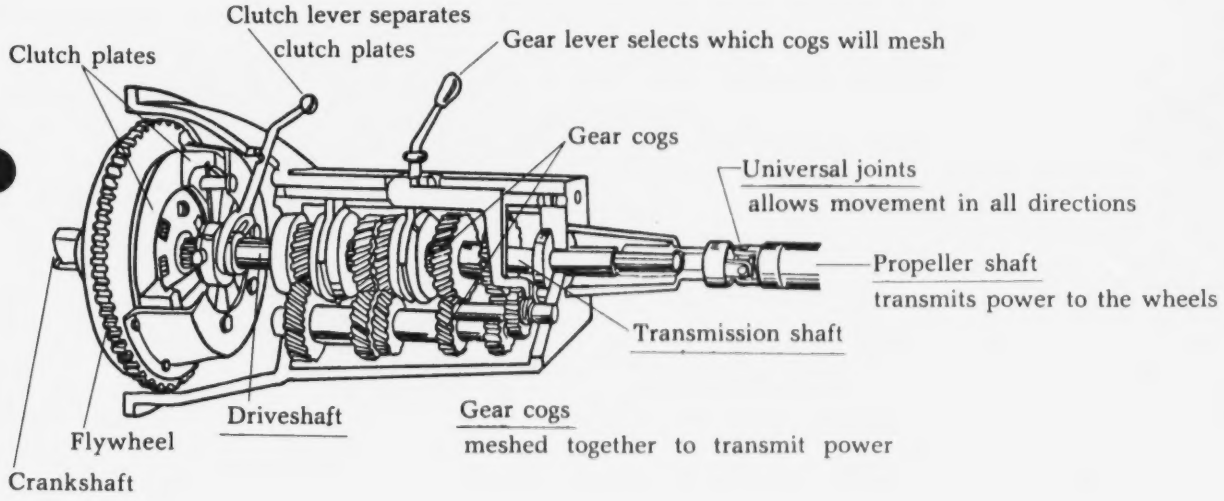
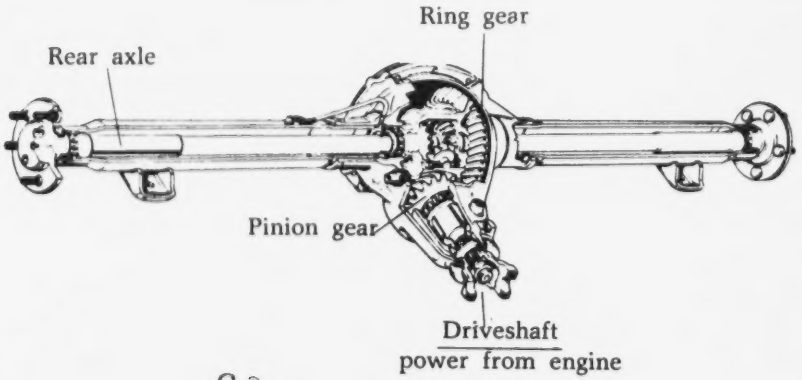


Figure 2: Differential



NOTES

GOAL/RATIONALE

The purpose of this lesson is to demonstrate how motion can be changed from one form to another and transmitted.

Concept Label	Concept Characteristics	Examples	Non-Examples
Transmission of Motion	The term "transmission of motion" refers to the idea that various types of motion can be changed from one form to another and be transmitted.	Rotary to linear (oil drilling) Rotary to to-and-fro (windshield wiper) Linear to rotary (foot treadle on old sewing machine).	Rotary to rotary (bicycle gear/chain) Linear to linear (hand saw and arm)
Energy	The ability to produce motion or change. Work is a form of mechanical energy. Energy can be potential (at rest) or kinetic (in motion).	Atoms splitting Steam from a boiler Wind blowing Heart pumping blood	A piece of paper A swing at rest A rock on the ground
Potential Energy	Potential energy is defined as the energy stored by an object due to its position. The object has the potential for doing work. Thus, the stored energy is called potential energy.	Water at the top of the falls. A tightly wound spring. A drawn bow.	Water spilling over the top of the falls. A spring unwinding. An arrow in flight after it is released from a drawn bow.
Kinetic Energy	Kinetic energy is defined as energy of motion. When an object is in motion, the stored, or potential, energy of the object is converted to kinetic energy. The object is then capable of doing the work.	Water spilling over the top of the falls. A spring unwinding. An arrow in flight after it is released from a drawn bow.	Water at the top of the falls. A tightly wound spring. A drawn bow.

Depending upon your time and the availability of devices similar to those photographed, you may take the class to actually see what happens.

ANTICIPATORY SET (Demonstration)

Briefly review with the pupils that in the model they built in Lesson 7, they used meshing bevel gears to change the direction of transmitting force. Then use the photos on Card 8 to elicit that these devices also involve changes of direction.

Build the white model yourself and enclose it in a shoe box so that only the input and output are shown. (See the LEGO® teacher's guide, page 9, for a specific picture.) Ask the pupils to suggest what might cause the output which they see.

OBJECTIVES

At the end of this lesson, the pupils will:

1. Identify situations where to-and-fro (linear) motion, rotary motion, or swinging motion can be changed from one form into another.

2. Identify the presence of potential and kinetic energy.

3. Change potential energy into kinetic energy.

4. Recognize how and where machines must overcome inertia in order to continue operating.

5. Use gears to assist in changing rotary motion to linear motion.

6. Gear up or gear down models which are changing rotary to linear motion or vice versa.

DIRECT INSTRUCTION/GUIDED PRACTICE

A. From the "black box" model used in the Anticipatory Set, point out that the drive wheel is using rotary motion while the output shows a to-and-fro action. Ask the pupils to identify which photo on Card 8 is similar to this model. (The car windshield wipers.) Have them build the white model on the inside of Card 8. Once it is built, they can see how the transfer of motion occurs.

To show that the width of the "swipe" can be altered, change the original connection for the axle from the bottom hole of the red beam to the next hole. The number of pieces in each kit limit the degree to which alterations can be made. Succesive alterations of this model are not germane to the lesson.

Build the yellow model. Be sure the pupils understand that they have changed to-and-fro motion to swinging motion. Have them suggest areas where such movement can be used, e.g., light switches, switches on "boom boxes," dampers, the window opener on photo three of Card 8, etc.

B. Have the pupils compare the huge modern generator shown in photo 1 and the antique machines, photos 2 and 3, of Card 9. All of the machines shown have similar components. Elicit from them that there is going to be rotary motion involved based on the wheels that they can see.

In addition, some pupils will realize that the rotary motion will be connected to swinging motion because they will note the rod connecting the treadle to the pulley wheel in photos 2 and 3. More details on this transfer of force will be discovered as they work with the model. Discuss the advantages of the foot treadle shown, i.e., the hands need to be free for working with fabric or raw wool.

In building the model, the two bushings are crucial in keeping the flywheel free so that it can turn.

Have the pupils build the model of the inside of Card 9. Once the model is complete, tell the pupils that just as the model stands with no motion, the unit has potential energy. Energy is the ability to do work. Potential energy is the energy present or available for use if it were set into motion.

Have the pupils start the model turning. (It helps to give the wheel a spin first.) The turning wheel demonstrates kinetic energy, the energy of motion. Call attention to the fact that inertia must be overcome in order to get the motion started. That is why giving the wheel a spin first helps.

Have the pupils remove the spinning wheel. Ask them to predict if the model will still turn by pumping the blue treadle (no). The reason the treadle does not now turn is that the red wheel is a flywheel whose purpose is to keep the motion, inertia, going so that the gear doesn't stop at dead center. (Be sure pupils are pumping the treadle, not moving the red beam by hand.)

To further illustrate the presence of inertia, have the pupils move the blue blocks from the ends of the flywheel to its center. Have them note how this makes the model difficult to keep moving. Suggest that they try the opposite tactic of adding more blocks than were originally used on the ends of the flywheel. How does this affect the spinning? (The added weight helps keep the flywheel turning because it gives added inertia for the gear to turn past dead center.)

C. Have the pupils build the white model on the inside of Card 13 and let them experience moving the gear along the rack. Point out that rotary motion (in the steering wheel) has been changed to to-and-fro motion (on the rack). Then refer to photo 1 on the front of Card 13. This is a picture of a sluice gate which uses a vertical version of this model. As the wheel is turned, the gears "crawl" along the rack and lift or lower the gate to control the flow of water. (They will later use this rack and pinion concept in a steering mechanism, Cards 19 and 20.)

Ask the pupils to suggest ways to make the rack move farther with one turn of the wheel. (Either use a larger turning wheel or a larger gear. The kit

has no larger wheels, but they can substitute a 24-toothed or 40-toothed gear. (To do this, they will need to increase the height of the blue beams through which the axle fits.) Depending on the time available, pupils can make the suggested alterations.

Have them build the yellow model and experience turning the wheel. Then refer to photos 2 and 3 on the front cover. Pupils should recognize that here again rotary motion is changed to to-and-fro motion or vice versa. Once they have worked the present model a few times, have them predict whether changing where the red beam is attached to the drive gear will alter the movement. (Yes) In effect, you have changed the length of the effort arm by changing the fulcrum and, therefore, speed is affected. Allow them time to investigate this change.

INDEPENDENT PRACTICE

Hint: Pupils need to view carefully all parts of the picture in order to correctly assemble the model. The angular plate is needed at the end of the double blue arm. The "holed" plates can fit in the wrong place so pupils need to plan ahead of time where the "holed" plates must be used to avoid running out of pieces.

Have the pupils build the oil rig model on the back of Card 9.

When the model is complete, they will enjoy having some time working with it.

CLOSURE

Use the model built from the back of Card 9 as a reference point. Tell the pupils you are going to ask them to demonstrate their understanding of certain key concepts by using the model.

1. Demonstrate kinetic energy. (The pupils should start the model running.)

2. Demonstrate potential energy. (The model is at rest.)

3. Point to rotary motion. (They point either to the steering wheel or to the gears.)

4. Point to to-and-fro motion. (They point to either the axles, the red "T" arms, or the front of the oil pump.)

5. Point to the parts which act as flywheels to help overcome inertia. (They should point to the red "T" arm.)

Have the pupils record these summary statements following the above review:

1. Kinetic energy is energy in motion.

2. Potential energy is energy at rest.

3. Inertia is the tendency of a body in motion to stay in motion and a body at rest to stay at rest unless acted upon by a force. Machines must overcome inertia.

4. Motion may have different forms.

5. Motion may be changed from one form to another.

Lesson 9 - Centrifugal Force and Motion
(Card 14)

NOTES

Materials Needed: Record player

GOAL/RATIONALE

The purpose of this lesson is to define centrifugal force, investigate how it can be produced, and learn how machines are affected by it.

Concept Label	Concept Characteristics	Examples	Non-Examples
Centrifugal force	Centrifugal force is defined as an outward force during rotation which causes an object to be thrown from the center and forced into a circular path. The word centrifugal means "center-fleeing" or "away from the center." The amount of force is affected by the circumference of the orbit, the speed of the rotating body, and the mass of the rotating body (opposite of centripetal force).	Rotating carnival rides which throw participants to the outside of the orbit. Playground merry-go-rounds which throw occupants to the outside of the apparatus as it whirls around.	Whirling a tin can on the end of a string keeps the can in a circular path because the string is held by a person standing in the center. The gravitational force directed towards the center of the earth holds the moon in an almost circular orbit.
Centripetal force	Centripetal force is defined as an inward force that causes an object to follow a circular path. The word centripetal means "center - seeking" or "toward the center." The amount of force is affected by the circumference of the orbit, the speed of the rotating body, and the mass of the rotating body. (Opposite of centrifugal force.)	Whirling a tin can on the end of a string keeps the can in a circular path because the string is held by a person standing in the center. The gravitational force directed toward the center of the earth holds the moon in an almost circular orbit.	Rotating carnival rides which throw participants to the outside of the orbit. Playground merry - go - rounds which throw occupants to the outside of the apparatus as it whirls around.

ANTICIPATORY SET

Ask the pupils to name specific amusement park "rides" in which they experience the sensation of being thrown outward. On the record player turntable, place some small objects. Have the pupils observe how these objects are thrown outward as the turntable rotates. Then tell them that there is a common factor between the carnival rides and the turntable which they will be investigating.

OBJECTIVES

At the end of this lesson, the pupils will:

1. Recognize centrifugal force as the force which throws objects away from the center of rotation.
2. Recognize where modern machines use centrifugal force in their operations.
3. Demonstrate centrifugal force as it affects the operation of LEGO^{R} models.

Step 5's illustration is somewhat misleading; the upright axle goes into the middle hole of the bottom 2 x 4 hold plate.

DIRECT INSTRUCTION/GUIDED PRACTICE

Have the pupils build the model of the merry-go-round as shown on the inside of Card 14.

Once the model is constructed, have the pupils explore the operation of the model. Tell them that the force which throws the "seats" outward is **centrifugal force.** Then ask them to note how turning the wheel faster affects the height to which the seats are thrown. (The faster the wheel spins, the higher the seats are thrown.) Tell them that speed is one of the variables which affects centrifugal force.

INDEPENDENT PRACTICE

Have the pupils build the model on the back of Card 14. (Hint: there is an eight-tooth gear, unseen, sandwiched between the two end blue sets of beams. The upright black axle is a "12" and just passes through the wheel. The angled axles are "6s".)

Once the model is built and operating, have them note the way the "tires" fly outward. Explain to them that this is the principle on which a governor on an engine or machine works. The purpose of the governor is to act like a brake so that the engine or motor does not exceed a set speed. As the wheels fly out, they trigger a switch which cuts off the energy source, thus slowing the engine or motor. For instance, in washing machines, the tub is set to spin no faster than a given speed on special cycles, e.g. "delicate fabric," "wash and wear," and "regular." However, in most modern equipment, a computer chip performs the function of a governor.

CLOSURE

Prior to asking the questions below, review the concept of centrifugal force and the variables that affect it.

Using either the model of the governor built or the picture on the back of Card 14, ask the pupils:

1. **What causes the tires or weights to fly outward?** (centrifugal force).

2. **How does speed affect centrifugal force?** (The faster the speed, the farther an object is thrown from the center.)

Lesson 10 - Pulley Systems
(Card 16, 15 optional)

NOTES

Materials Needed (optional):
Pulleys of various sizes.

GOAL/RATIONALE

The purpose of this lesson is to describe the pulley, investigate pulley systems, and show how these systems make work easier.

Concept Label	Concept Characteristics	Examples	Non - Examples
Pulley	A pulley is a simple machine. It makes work easier by changing the direction of a force. Two or more pulleys can be used together to decrease the force needed to move an object. A pulley can be fixed in one spot or moveable. It usually consists of a wheel with a groove in the middle of the rim.	Block and tackle Apparatus at the top of a flag pole	Gear

ANTICIPATORY SET

Refer pupils to the school's flag pole. Elicit from them that to raise the flag, a device has to be fixed near the top of the pole. Most pupils will know that this is a pulley. Ask them to suggest areas in real life where pulleys are used (cranes, tow trucks, to pull up scaffolding on which workers stand, to raise and lower the cargo net in the gym, etc.).

OBJECTIVES

At the end of this lesson, the pupils will:

1. Identify a pulley as a grooved wheel around which a rope, cable, or chain is placed.
2. Demonstrate that a single fixed pulley changes only the direction of the force.
3. Demonstrate that combinations of pulleys, known as block and tackle, make work easier.
4. Relate the use of the formula W = F x D to the use of pulleys.
5. Recognize that pulleys are related to levers.

DIRECT INSTRUCTION/GUIDED PRACTICE

Have the pupils build the white model on Card 16.

Hint: Be sure the pupils follow Step 1 exactly, otherwise the framework will sway because it is not sufficiently braced.

To fasten the thread at Step 4, slip it inside the bushing before pushing the bushing around the axle. Once the model is built, identify the wheel on the crossbar as a pulley. Point out that the axle serves as a fulcrum around which the string or lever is turning. Therefore, the work done is related to the force used in turning the ratchet and the distance, or the amount of string needed, to lift the weight.

Have the pupils record the number of turns needed to lift the weight from the green building plate to the crossbar ($3\frac{1}{2}$). Tell them that the model is a **fixed** pulley. Tell them that the advantage of using a fixed pulley is to change the direction of the force, i.e., you pull down to get a weight to rise.

Alter the model so that it looks like the yellow model.

Hint: When fastening the weight this time, note that the blue stud beam has to be behind the center, otherwise the weight tips over and the pulley thread comes off.

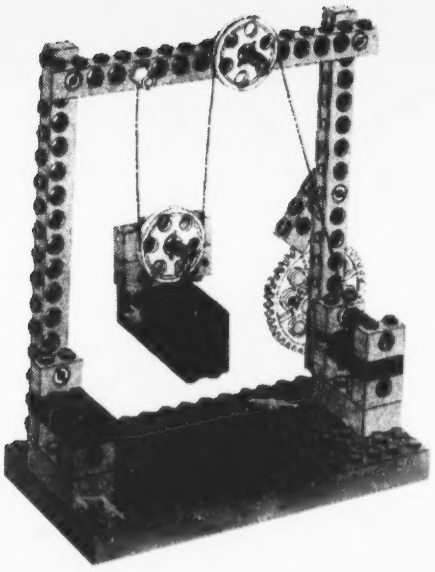
Ask: **Why has a second pulley been added?** (Many will intuitively know that the load will be easier to lift.) Identify this combination of pulleys as a **block and tackle.** The block is the pulley; the tackle is the thread. Have them operate the model to experience the ease with which the weight now rises. Then have them record the number of turns needed to raise the weight to the cross arm (7).

By comparing the number of turns the white model required with those needed by the yellow model, the pupils should see that twice as much string has been used. Therefore, the distance portion of the work formula has been increased; the force needed was decreased.

Identify the 40-toothed gear as a ratchet. Ask: **What would happen if the four stud beam above the ratchet were removed?** (The weight would fall back down unless you keep your hand on the wheel.) Essentially the ratchet serves as a counter weight.

The rachet also involves gearing. To illustrate this, ask the pupils to predict **if a 24-toothed gear replaced the 40-toothed gear, would the effort needed to life the weight be greater or less?** (greater). Have them test their predictions by altering and then operating the model.

For your information: The number of turns needed to raise the weight is 7 with both gears because you are winding up the same amount of thread. By using a smaller wheel you must turn harder because the distance, amount of thread wound up, is the same, and the weight lifted remained the same; therefore, if W = F x D, the force, the effort into turning the wheel, must increase.



INDEPENDENT PRACTICE

Have the pupils build the model on the back of Card 16; then let the pupils spend some time operating it. They can try different sized winches for reeling up this weight also, if there is time.

Using Card 16, have the pupils note the number of strands supporting the weight. Ask: **In the white model, Step 6, how many strands are there?** (1) (You do not count the strand which connects the last pulley to the winch.) **In the yellow model, how many strands are there?** (2) **On the back page, how many are there?** (3)

Remind the pupils that the red weight weighs 54 grams.

Ask:

1. In the white model, **if there were no friction, how much force would be required to lift the weight?** (54 grams of effort) **Why?** (A single fixed pulley only changes the direction of the force; it does not lessen the effort, because only one strand supports the weight.

2. **In the yellow model, assuming all else is equal, how much effort would it take?** (27 grams) **Explain your answer.** (There are two strands, each of which supports the weight equally.)

3. **On the back page model, how much effort would be needed?** (18 grams) **Explain your answer.** (There are three strands supporting the weight, i.e., 54 divided by 3 = 18.)

You may need to point out that the bushing on the top cross piece is really acting like a pulley.

Again ask the pupils to make the assumption that all weight attachments are equal and that you have counted the number of turns the winch requires. Then ask:

1. **If the white model takes five turns to raise the weight to the top, how many turns will the yellow model require?** (10) **Explain your answer.** (Twice as much thread must be wound up.)

2. **Using the back page model, how many turns would be needed?** (15) **Explain your answer.** (Three times as much thread must be wound up.)

Help the pupils relate these figures to the formula W = F x D. As the force (54g to 27g to 18g) became less, the distance, measured by the number of turns of the winch, became more, (5 to 10 to 15).

CLOSURE

Use card 16 as a reference. Have the pupils record the answers as either white model, yellow model, or back page. (Alternate method: Using whole-class response techniques, have the pupils hold up one finger for white, two fingers for yellow, and three fingers for back page. If two answers are correct, they can use both hands. Do not permit pupils to hold up their answers until you say, "Show.")

1. **Which model(s) shows a single fixed pulley?** (white)

2. **Which model(s) shows a block and tackle?** (yellow and back)

3. **Which model(s) will require the most effort to lift the weight?** (white)

4. **Which model(s) will require the least effort to lift the weight?** (back page)

5. **Which model(s) will require the greatest number of turns on the winch to lift the weight?** (back page)

6. **Which model(s) will require the fewest number of turns?** (white)

Review with the pupils the correct answers and the reasons for those choices. Information Sheet #1 "Pulley Systems" may be given to the pupils at this time.

BLOCK AND TACKLE

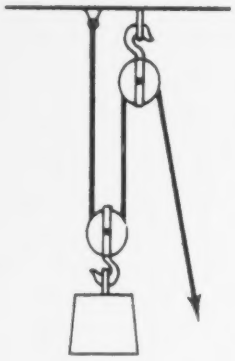
By using pulleys, it is possible to transmit power in a way similar to levers and gears.

For pulleys, what is "saved" in effort is "lost" in the amount of pulling. In other words, the greater the number of pulleys (wheels), the longer the rope to be pulled.

A block and tackle arrangement consists of two or more pulleys acting together.

If the rope is passed around only one pulley, there will be no mechanical advantage, although a more comfortable working position can be achieved. If the rope is passed around two pulleys, a mechanical advantage is gained, because you have more ropes supporting the load. The more ropes supporting the load, the less effort you will need to lift the load.

(1) Fixed pulley



(2) Moveable pulley

NOTES

Materials Needed (optional):
toy cars

The concepts involved in this lesson can become quite complicated and unrelated to the focus of the unit. Therefore, only information relevant to this unit is supplied.

GOAL/RATIONALE

The purpose of this lesson is to investigate parallel steering and trapezium steering using a rack and pinion mechanism, to relate these concepts to the wheel and axle, and to show the advantage of trapezium steering.

Concept Label	Concept Characteristic	Example	Non-Example
Parallel steering	Parallel or "parallelogram" steering refers to the geometric configuration of the steering assembly. The front of Card 19, photo 3, shows an example of a parallel wheel alignment. In an actual turning situation, the inner and outer wheels have equal turning radii.	A coaster wagon Older model hay wagon Toy cars Soap box cars	Most modern standard cars and sports cars Card 19, photos 1 and 2
Trapezium steering	Trapezium or "trapezoidal steering" refers to the geometric configuration of the steering assembly. The front of Card 19, photo 4, shows an example of trapezium wheel alignment. In an actual turning situation, the inner wheel has a smaller turning radius than the outer wheel, thus making it possible for the vehicle to turn more sharply (See diagram, page 32, LEGO® Manual.)	Steering systems on most modern standard cars and sports cars Card 19, photos 1 & 2	Coaster wagon Older model hay wagon Toy cars Soap box cars

They can leave the model intact while learning the difference between parallelograms and trapeziums, Card 3, Direct Instruction.

ANTICIPATORY SET (Pupil Activity)

Using Card 10, have the pupils build the white model. Then have them design an obstacle course on their desktops by either using kit components (see page 31 of the LEGO teacher's guide) or items from their desks (scissors, pencils, erasers, etc.). Using the model made, have them maneuver it through the obstacle course. Tell them that they are going to be investigating some factors related to making steering easier.

OBJECTIVES

At the end of the lesson, the pupils will:

1. Differentiate a parallelogram from a trapezium by building each geometric figure.
2. Place wheels on models so that they exhibit parallel steering.
3. Place wheels on models so that they exhibit trapezium steering.
4. Relate rack and pinion steering to gears.

5. Demonstrate the advantage of trapezium steering by showing that turning sharp corners is easier.

6. Explore different steering systems and identify the advantages, disadvantages, and some common uses of each.

DIRECT INSTRUCTION/GUIDED PRACTICE (A)

The Guided Practice sections can be broken at the lettered sections.

Use the first page of the inside of Card 3. Have the pupils build the top model. Identify it as a **parallelogram**, i.e., the opposite sides are exactly equidistant from each other, or parallel. Have them move the sides so that they can see the movement.

Have the pupils look carefully at the white model they just built from Card 10. Tell them the wheels are attached in parallel. Ask them to look at the front photos on Card 10. Is **the white model like photo 1 or photo 2.** (Photo 1. - The baggage cart is steered only as the man directly guides it.)

Start Study Master #1 for recording data collected on each of the steering systems. Have the pupils use Study Master #2 (obstacle course). They should note carefully the ease with which each model can be maneuvered. Maneuverability is a factor to be considered under "advantage" or "disadvantage." Another factor to be considered is cost. Suggest they base their judgment on the number of components needed to build any particular model.

Have them alter the model as shown for the yellow model.

Hint: Keep the white model intact; it becomes the rear wheel section of the "wagon."

After they compare this model to photo two, have the pupils maneuver the "wagon" through the obstacle course. Also have them note that, in order for the front wheels to turn sharply, the body must "sit high." Ask what the added height does to the **stability** of the vehicle. Explain that, simply put, stability is resistance to tipping. Therefore, the higher the vehicle, the more easily it will tip.

Have them record the advantages and disadvantages of this model. (On the teacher's copy of the chart are some possible answers.) Be sure they understand that both this model and the original push cart model are parallel steering.

Use Card 19. Explain that photo three shows a parallel arrangement as they had used on the push cart and wagon they made from Card 10. Remind them that they have discovered that parallel steering has some disadvantages, particularly when trying to turn sharply.

GUIDED PRACTICE (B)

Use Card 3. Have them construct the bottom model on the first inside page. Identify this as a **trapezium**, only two sides are parallel to each other. Have them move the sides so that they contrast this movement with that of the parallel model. Noting carefully the sharper angled movement of the trapezium is crucial to understanding the advantage of trapezium steering. Photo four, Card 19, shows a trapezium alignment of wheels.

Study Master #4, "Parallel vs. Trapezium Steering" can be made into a transparency so you can help point out the differences.

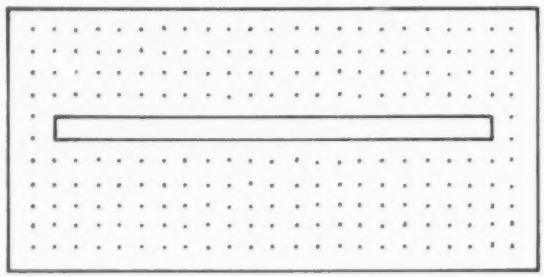
Have the pupils study the illustration for step four of the white model on Card 19 and contrast it with the yellow model.

Study Master #3 can be made into a transparency to show them where the tie rod is in a car.

Help them see that there is a difference in the angle which results from where the tie rod, red 2 x 8 stud plate, is attached.

Placing the model here allows the pupils to see the relative differences between parallel and trapezium steering because they can compare the positions of the tie rod, red beam, to the edge of the building plate.

Have them build the white model, **but** rather than setting the two anchoring blue stud beams on the end of the green building plate as shown, have them turn the plate 90 degrees and place the beams exactly in the center of the green building plate.



Have them maneuver the steering shaft, gray connector peg, several times as they note where the wheels end, related to the edge of the green plate.

To more clearly see the difference between parallel and trapezium steering, have them affix a blue beam to the outside of each front wheel axle. These beams act like pointers. If the pupils turn the steering wheel to its maximum point, they will see that the two pointers remain equidistant on parallel steering; however, with trapezium steering, there is a noticeably greater spread. By making a pencil mark at the pointer's end, they can measure the difference.

Because of the complexity of building the universal joint as shown on the back of Card 20, you may want it to be an optional activity. However, building it does aid in understanding the way universal joints are beneficial in steering mechanisms which must turn. There is a "Teacher Information Sheet" with more specifics included for your use. There are also black line masters which may be used for transparencies to help the pupils see one placement of a universal joint.

Have them alter the model to trapezium steering as shown in the yellow model. Maneuvering the steering shafts on this model will demonstrate how much more sharply trapezium steering turns, or "corners."

GUIDED PRACTICE (C)

Use Card 20. Because trapezium wheel alignments are commonly connected to rack and pinion steering gears, have the pupils build the model on the inside of Card 20. (They used a simple application of this rack and pinion on Card 13.) When the model is complete, allow time to operate it. Be sure they observe carefully the sharp angle at which the inside wheel turns. Refer to photo two on the front of Card 20 for an example of a similar arrangement in an automobile. The front cover shows trapezium wheel alignment; their model is parallel.

INDEPENDENT PRACTICE

Have the pupils build the car shown on the back of Card 19. Tell them this is an example of parallel steering. Allow time to permit maneuvering this car. Have them identify specific parts: wheel and axle, universal joint, rack and pinion. You may ask them to change the steering gear so that the steering wheel and 8-tooth gear are directly operating the rack and pinion. Have them note what happens. (The direction for steering is opposite, i.e., to turn the wheels left, you have to turn the steering wheel to the right).

CLOSURE

Review with the pupils and have them record these concepts in their notebooks:

1. There are two basic arrangements for steering systems: parallel and trapezium.

2. Parallel steering systems have wheels which remain equidistant from each other; therefore, turning sharply is more difficult.

3. Trapezium steering systems have wheels which are not equidistant; therefore, maneuvering is easier because the inside wheel can turn more sharply.

4. Rack and pinion gear systems help make steering easier.

LESSON 11, STUDY MASTER NO. 1
"STEERING MECHANISM"

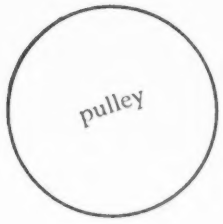
Type of Steering/ Placement of Wheels	Advantages	Disadvantages	Common Uses

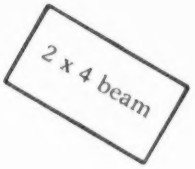
LESSON 11, STUDY MASTER NO. 1
"STEERING MECHANISM"

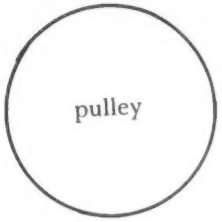
Type of Steering/ Placement of Wheels	Advantages	Disadvantages	Common Uses
Pushcart, Parallel	Easy to make Cheap	Hard to maneuver	Pushcarts, Baggage Carts, Rickshaws, Sulkies
Wagon, Simple Parallel	Easier to maneuver Fairly cheap Can carry a big load Can back up without turning around	Tips easily if turned too sharply	Small wagons, soap box cars, toy cars
Trapezium			

SAMPLE

STUDY MASTER NO. 2, LESSON 11
OBSTACLE COURSE



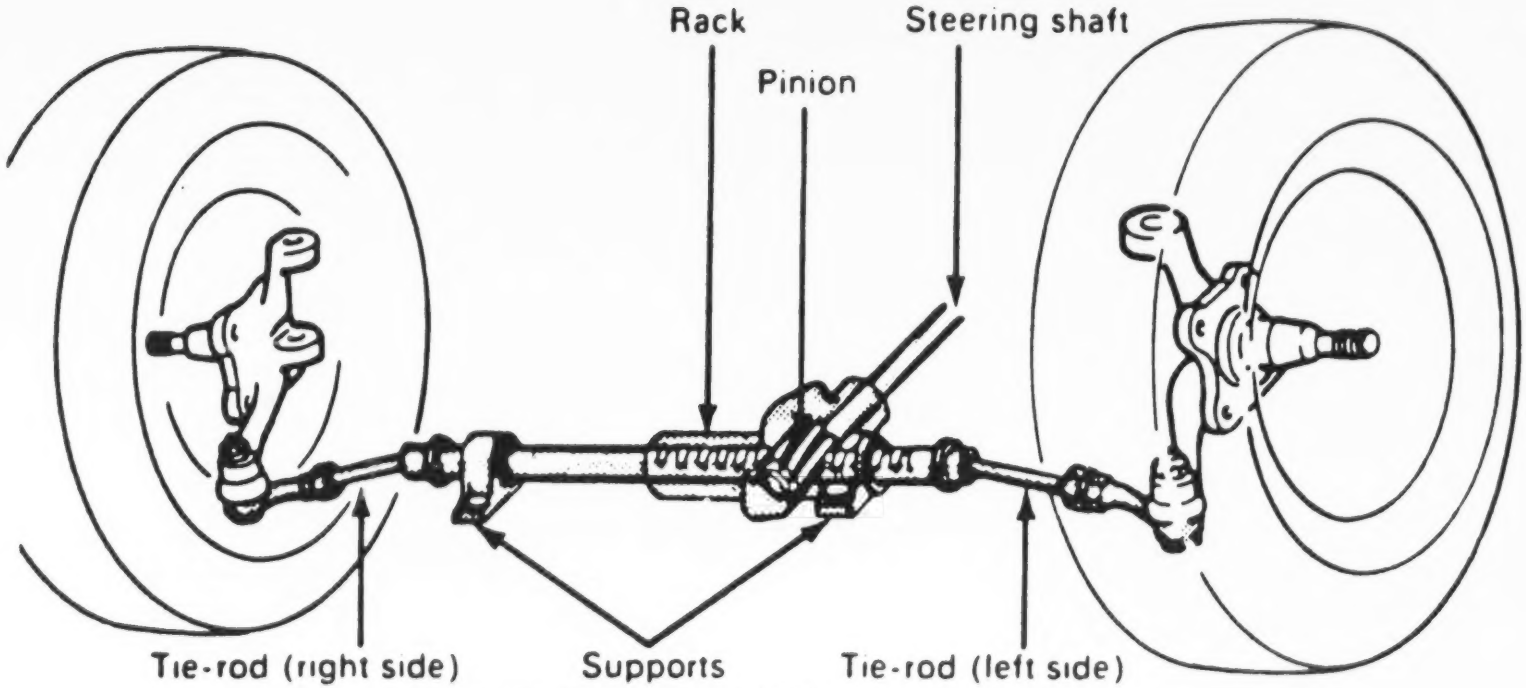




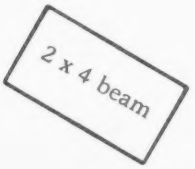
STUDY MASTER NO. 3

Lesson 11

"TRAPEZIUM/RACK AND PINION STEERING"



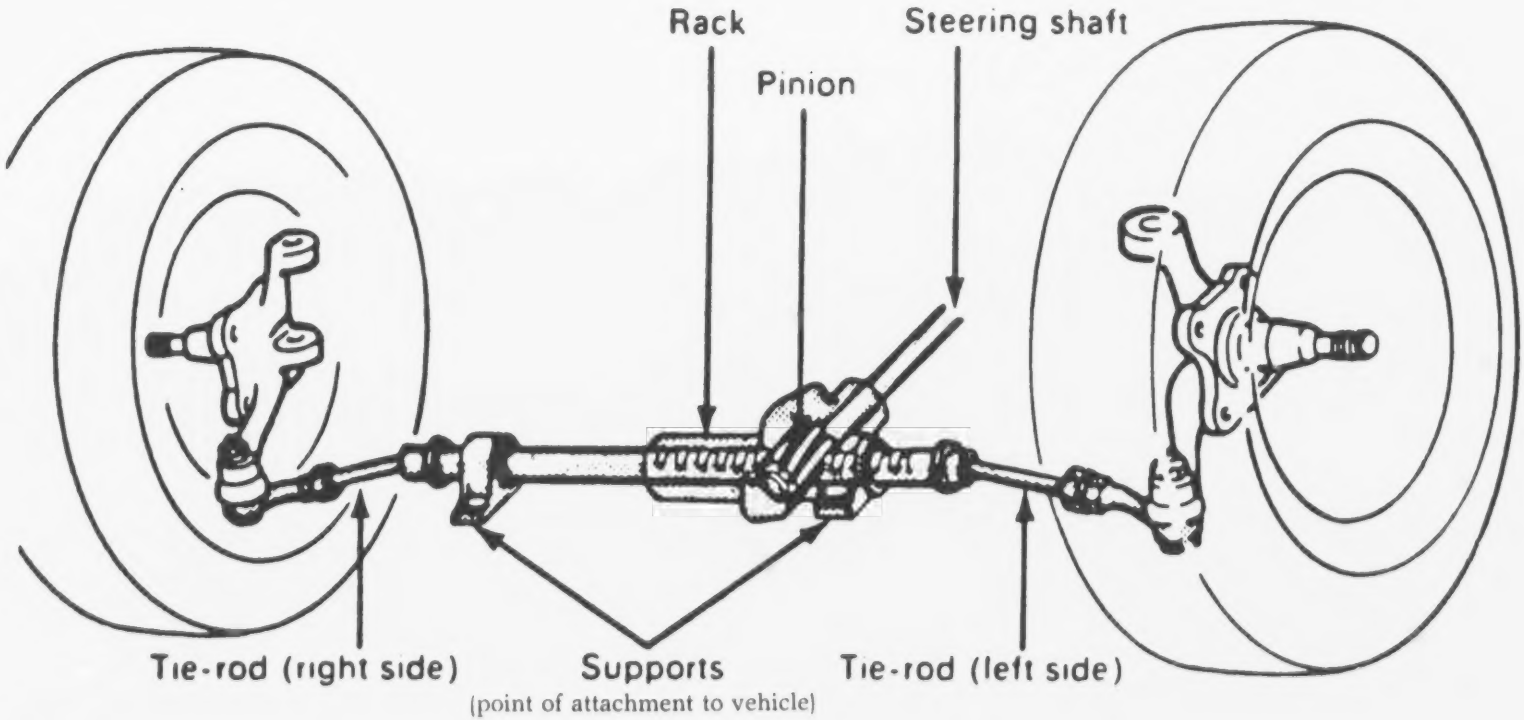
STUDY MASTER NO. 2, LESSON 11
OBSTACLE COURSE



STUDY MASTER NO. 3

Lesson 11

"TRAPEZIUM/RACK AND PINION STEERING"



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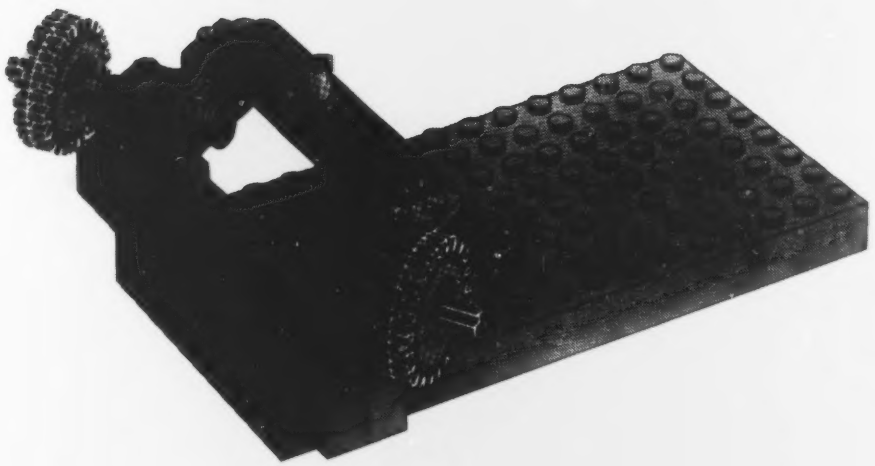
STUDY MASTER NO. 4

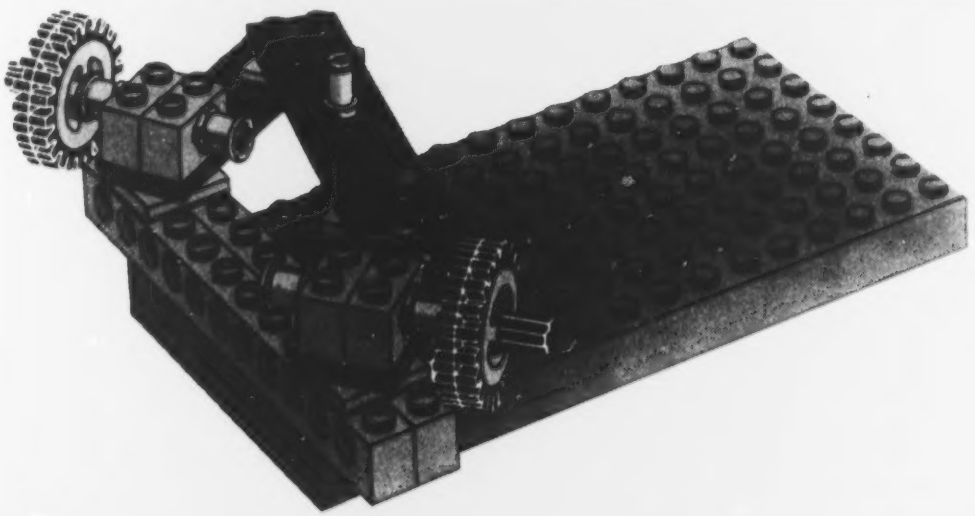
Lesson 11

Parallel versus

Trapezium Steering



PARALLEL



TRAPEZIUM

Lesson 12 - Mechanical Advantage
(Parts of Cards 4, 5, 7, 11, 12, 15, 16)

NOTES

Materials Needed (optional): calculators, Pupil Lesson 2 Chart, Study Masters from Lesson 2

GOAL/RATIONALE

The purpose of this lesson is to demonstrate that mechanical advantage is a way of measuring the ease with which a simple machine performs work.

Lego (for use in lesson on mechanical advantage and energy).

Concept Label	Concept Characteristics	Examples	Non-Examples
Mechanical Advantage	Mechanical advantage is a measure of the amount by which a machine increases a force. Ideal mechanical advantage neglects the effect of friction. Actual mechanical advantage considers the effect of friction and is always less than the ideal mechanical advantage. Lubricants are used to reduce friction.	Using a lever to lift a rock. Using pulleys to load a boat onto a trailer. Using a bicycle instead of walking.	Lifting a box with your arms. Weeding the garden by hand.

ANTICIPATORY SET (Teacher Demonstration)

Have the pupils study the photographs on the front of Cards 4, 5, 7, 11, 12, 15. Ask: **What do all of these pictures have in common?** For instance:

Why doesn't the man on Card 4 lift the box by hand? Why doesn't the man on Card 15 lift the car by hand? Why use an egg beater or a drill, etc.? Elicit that in all of these instances, machines are being used which make the work easier. Then tell them that they are going to learn a way to determine or measure how much easier the work will be, i.e., what advantage do the machines give?

OBJECTIVES

At the end of this lesson, the pupils will:

1. Define work as using force (a push or pull) to move an object.
2. Recognize that mechanical advantage (M.A.) is a way to measure the degree to which a machine helps make the work easier.

3. Recognize that friction is always present in the operation of any machine; therefore, the actual M.A. will be less than that computed.

4. Demonstrate how to determine the relative mechanical advantage of various specific simple machines.

DIRECT INSTRUCTION/GUIDED PRACTICE

This section can be broken into several parts, either by type of simple machine, or by taking lever-related machines as one lesson and inclined plane-related machines as another lesson.

Have the pupils refer to the chart they developed during Independent Practice in Lesson 2, Study Master #1. Put this drawing on the overhead or board. Point out the various parts.

Ask: **"When are the fewest number of paper clips needed - when the effort arm is longest or shortest?** (longest) **What happened when the effort arm became shorter?** (More paper clips, i.e., more effort, were needed) Point out again that as the effort arm became shorter, the resistance arm became longer. This difference has significance for determining how much the lever can help in doing the work needed.

Tell them that by computing the ratio between the effort arm distance, or length, and the resistance arm, you can determine the **mechanical advantage** of a lever. Mechanical advantage is a way of expressing in numbers how much assistance a particular machine will give.

Lesson 12, Study Masters #1, 2, and 3, may be used here to aid in clarifying concepts.

For instance, if you use the holes of the beam used in making a lever as measuring units, you can divide the effort arm's length (e.g., 24 holes) by the resistance arm's length (e.g., 4) and get a figure of 6 (24/4 = 6) The 6 of your answer means this lever would multiply the effort put into it six times. Thus if ten pounds of effort were put on the effort arm, you could lift 60 pounds of resistance. (Be sure the pupils understand that this figure is the ideal, not actual, mechanical advantage. Friction will always play a role in decreasing ideal mechanical advantage to actual mechanical advantage.)

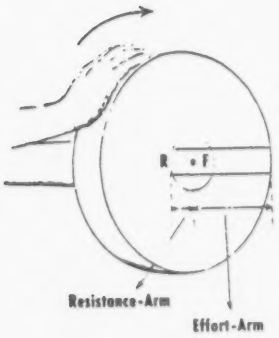
Have the pupils use the data from their charts in Lesson 2, Study Master #1, to compute the mechanical advantage of other lengths of the levers they constructed. (Using calculators may speed the math part of this work.) When they have computed the calculations, ask them to make a summary statement regarding the relationship of the length of the effort arm to M.A. (The longer the effort arm, the greater the M.A.)

Have the pupils refer to the drawing of the block and tackle of Lesson 12, Study Master #4. Have them

understand that a pulley is just like a "bent" lever; the fulcrum is the center of the axle around which the pulley pivots. Thus the supporting ropes on a pulley are like the effort arm of the lever. The easy way to determine the M.A. is simply to count the number of supporting ropes in a block and tackle. Refer them to the inside of Card 16, Step 6. Ask them what the M.A. would be for this model if no winch were used. (M.A. = 1. A simple fixed pulley only changes the direction of the force. There is only one supporting rope.) Then direct them to the yellow model and repeat the question. (M.A. = 2. There are two supporting ropes.) Repeat the questions for the back page model. (M.A. = 3. There are 3 supporting ropes.)

See Lesson 12 Study Master #5. "M.A. for Wheels and Axles."

Use the front photographs on Card 5 to elicit that the belts pictured here are like continuous pulleys. Remind them that the belts are connected to wheels and axles. The wheel and axle is also like a circular lever. The center of the axle is the fulcrum. The effort arm is from the rim to the center, and the resistance arm is from the edge of the axle to its center if force is gained as when you use a winch to help raise a heavy load. (The effort and resistance arms are reversed if speed is gained, as when you spin a top. But the ratio so far as M.A. is concerned is the same.)



Thus the M.A. for a wheel and axle can also be found by dividing the effort arm by the resistance arm.

Have the pupils build the model through Step 4 of Card 5, omitting the left hand axle. Let them compare this model to the drawing. If they measure the effort arm and the resistance arm, they will find that the ratio is roughly 6 to 1. (Because the axle is so small, it is hard to be accurate.) Therefore, the M.A. is 6. Thus this wheel and axle would multiply the effort exerted 6 times, or multiply the speed and distance 6 times. For instance, if a 30 pound weight were attached to the axle, it would take 5 pounds of effort to raise it one foot (30/5 = 6) If you gave the axle one turn, an object on the wheel would travel six times as far.

Have the pupils look at Step 5 on the inside cover of Card 5, noting that the two driven wheels are the same size. Explain that this arrangement will not increase the original mechanical advantage beyond the 6 of the wheel and axle connection, because both wheels are the same size. Look at insets 2 and 3. **Will there be an M.A.?** (Yes. The wheels are different sizes.) Help the pupils understand that M.A. for belt transmissions can also be calculated by comparing the relative size of the two wheels which are connected. The wheel measurements can be made by circumference, diameter, or radius, whichever is most convenient.

Because the bushing is so small, measuring the diameter rather than radius or circumference is easiest here.

Have the pupils compare the two wheels, i.e., the bushing and the grey pulley wheel. They will find that the ratio is approximately 4:1. Thus this arrangement will give a mechanical advantage of 4. Because the mechanical advantage of the steering wheel and the axle connection is 6, the total mechanical advantage for insets 2 and 3 is multiplied. Remind the pupils that slippage will lower the actual mechanical advantage.

If they do not recall the work, use the Card 12 pictures, or have them build the model to again compute the ratios.

Gears are closely related to wheels and axles. The M.A. is even simpler to determine; just count the number of teeth for the gears which mesh. Refer them to the work done in Lesson 7, Gears. In the Independent Practice section of that lesson, they determined the gear ratios of the yellow and red models on the insides of Card 12. Those ratios are also the M.A. for these two models. (Yellow = 25; Red = 15.) Thus in using the yellow model, an effort input of five pounds on the drive gear would produce 125 pounds of force from the final driven gear (25 x 5). For the red gear assembly using 5 pounds of effort, you would receive 75 pounds of force (5 x 5 x 3).

Ask the pupils to name the two remaining simple machines for which they have not yet learned a method of assessing M.A. (inclined plane and screw.) Tell them that these simple machines have a related method of determining M.A.

Lesson 12 Study Masters #6, 7, and 8 may be used there.

In the case of the inclined plane, you compare the effort distance to the resistance distance.

This procedure is very similar to the computation they learned for levers. Refer to Lesson 12, Study Master #6. Using that drawing, point out that the resistance distance is the three feet that the barrel would have to be lifted onto the truck. The effort distance in the six-foot ramp the barrel was rolled up. By dividing the effort distance (6) by the resistance distance (3), you find the M.A. is 2. Thus using the 6 foot ramp to move the box, you could put in only ten pounds of effort and still move the 20 pound box into the truck.

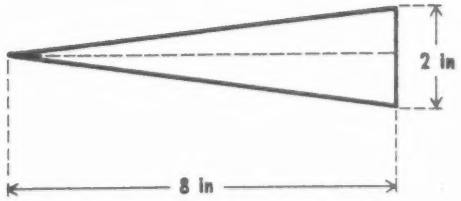
D	X	F	=	W
3		20		60
6		10		60

Have the pupils compute how much effort would be needed if the ramp were 10 feet long. (6 pounds of effort)

$$\frac{W}{60\text{ft-lb}} = \frac{D}{10x} \times \frac{F}{6}$$

Lesson 12 Study Master #9 may be used here.

The wedge - a double inclined plane, is similar. You compare the thick end of the wedge with the total length of the wedge. For instance, if you have a wedge that is 8 inches long and 2 inches wide at its blunt end, the M.A. = 4. Therefore, in using this wedge to split wood, if you hit it with a force of 25 lbs., it would exert a force of 100 lbs. against the log you are splitting.



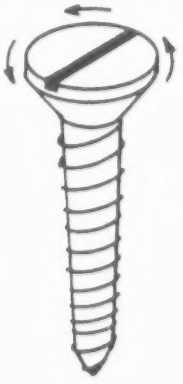
Ideal M. A. = 4

Show the pupils that this relationship can be written in a short form:

$$\frac{\text{Effort Distance}}{\text{Resistance Distance}} = \text{M.A.}$$

Have the pupils compute the M.A. of a wedge that is three inches at its thick end and nine inches long. (M.A.=3) If you hit the wedge with 30 lbs. of force, what would be the output? (90 lbs.; 30 x 3 = 90)

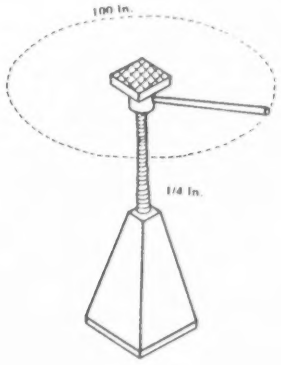
Remind the pupils that a screw is an inclined plane wrapped around a core. When the head of the screw makes one complete turn, the screw moves the width of one pitch.



You will have to decide whether the pupils are ready for this computation. Study Master #10 may be used here.

To find the M.A. of a screw, compare the circumference of the head with the size of the pitch. For instance, if the head has a 2 inch circumference, and the pitch is 1/8 inch, the M.A. is 16. Have the pupils associate this ratio with raising an auto on a jack. The distance you must turn the handle is like the head of the screw. If the handle travels around a 100 inch circumference as you turn, and the pitch raises the

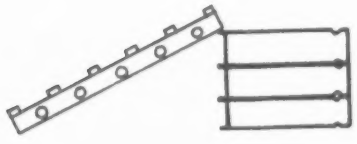
car $\frac{1}{4}$ inch, the M.A. would be 400. Thus if you exerted 10 lbs. of effort, the jack screw would put out 4,000 lbs. of force.



Remind the pupils that friction always lessens the M.A. This is particularly true with the screws.

INDEPENDENT PRACTICE

Ask the pupils to build an inclined plane using an 8 x 1 stud beam. All they need to do is slant the beam against something, e.g.,



Then tell them to build an inclined plane which will have a greater M.A. (The 8 x 1 beam can be replaced with either of the two longer stud beams. They could also lower the beam.)

Using gears, have them build a gear train which would give a M.A. of 5 (They need to connect a 40 toothed gear to an 8 toothed gear.) Then tell them to change the M.A. so that it is less. (They can substitute the 24-toothed gear for either of the original gears or they can mesh gears of equal size.)

Tell the pupils to arrange a block and tackle so that it gives an M.A. of 2. (There need to be two "supporting ropes.") Ask them how they would increase the M.A.

(Add more supporting ropes, i.e., they will need more pulleys.) Because of time factors and the parts available, you can decide whether to have them actually build their suggestions.

CLOSURE

Review with the pupils and have them copy these concepts related to Mechanical Advantage (M.A.):

1. Mechanical advantage is a measurement of the degree to which a machine makes work easier.

2. Friction or slippage will always lessen the amount of mechanical advantage any machine gives.

3. The mechanical advantage for an inclined plane, a wedge, or a lever is computed by dividing the effort arm, or effort distance, by the resistance arm, or resistance distance.

4. The mechanical advantage for gears is calculated by computing the ratio of the teeth of the meshing gears.

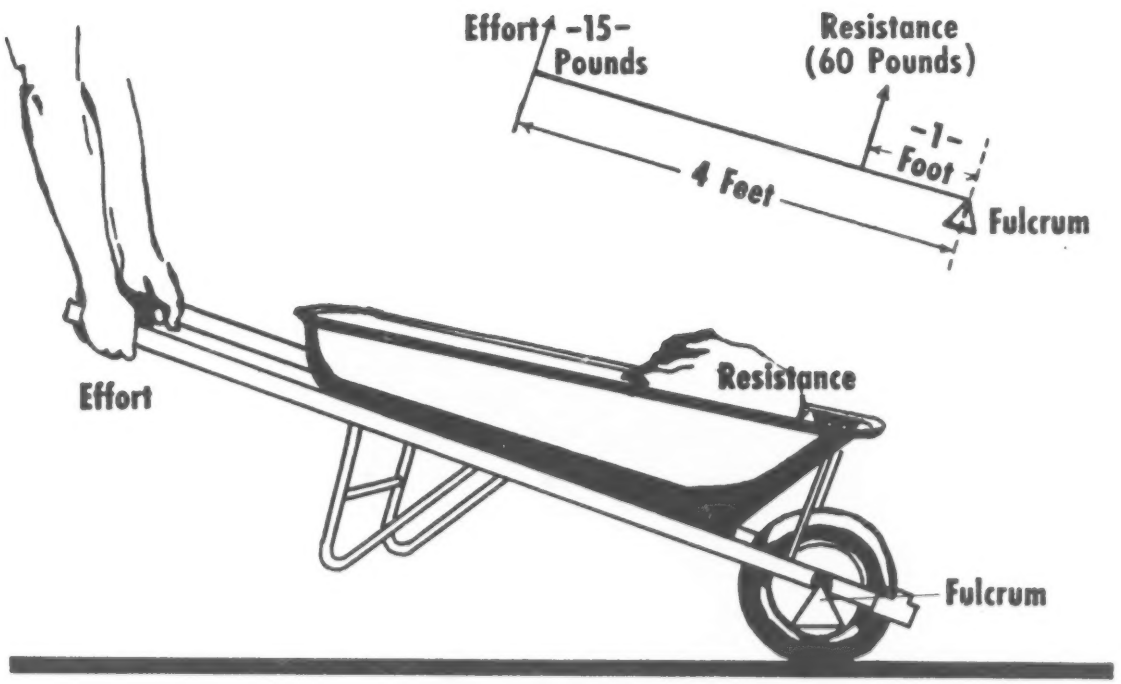
5. The mechanical advantage for wheel and axles is calculated by computing the ratio of the circles involved.

6. The mechanical advantage for screws is calculated by computing the ratio between the circumference of the screw head and the pitch of the screw.

7. The mechanical advantage for pulleys is calculated by counting the number of supporting ropes.

To further reinforce the concepts taught, have the pupils compute the M.A. for these drawings. Study Master #14 is provided. Be sure to review and explain the correct answers at the end of the lesson.

STUDY MASTER NO. 1
LESSON 12

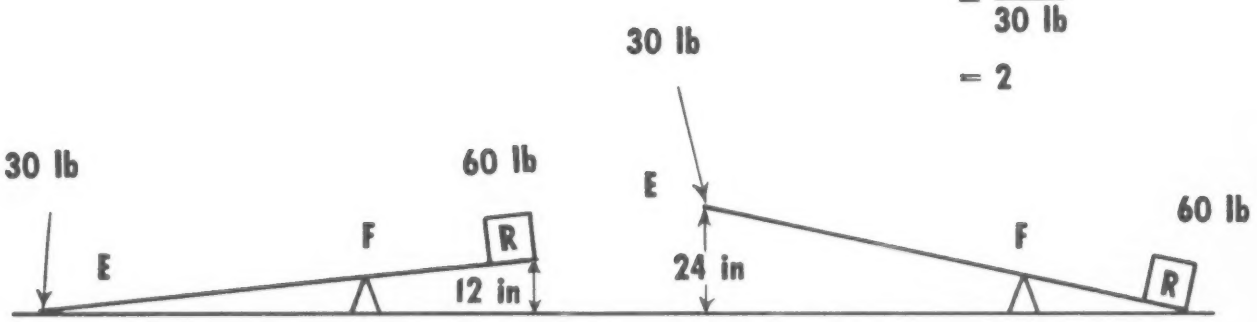


STUDY MASTER NO. 2
LESSON 12

$$\text{Actual M. A.} = \frac{\text{Resistance}}{\text{Effort}}$$

$$= \frac{60 \text{ lb}}{30 \text{ lb}}$$

$$= 2$$

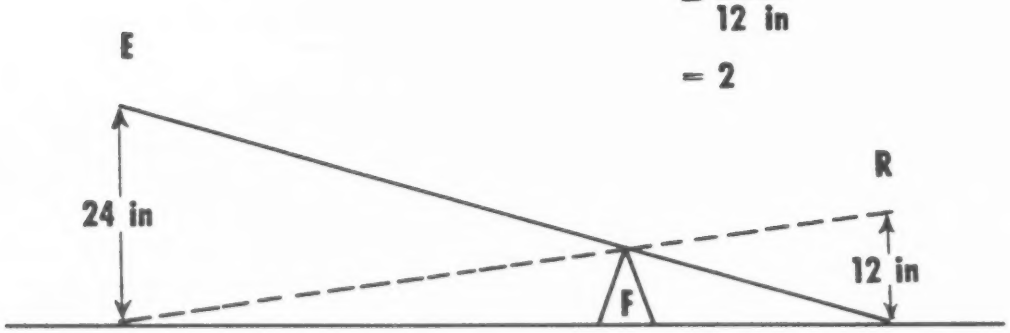


STUDY MASTER NO. 3
LESSON 12

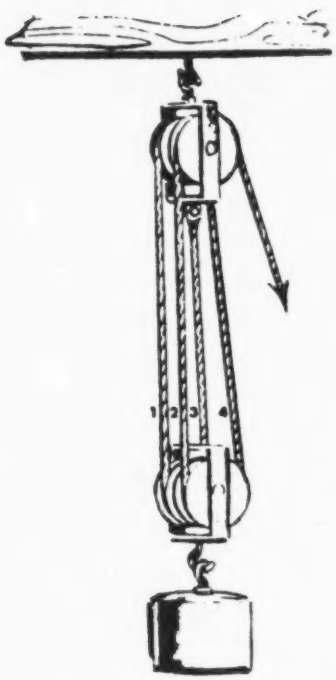
$$\text{Ideal M. A.} = \frac{\text{Distance Effort Moves}}{\text{Distance Resistance Moves}}$$

$$= \frac{24 \text{ in}}{12 \text{ in}}$$

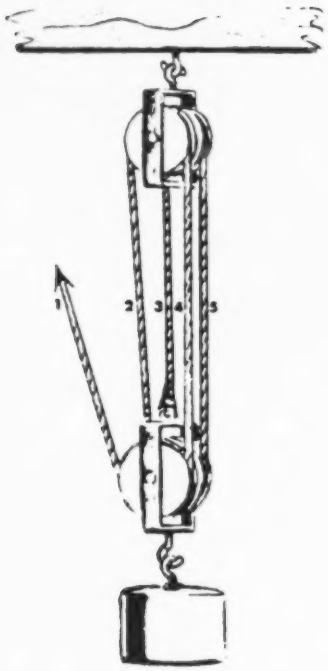
$$= 2$$



STUDY MASTER NO. 4
LESSON 12

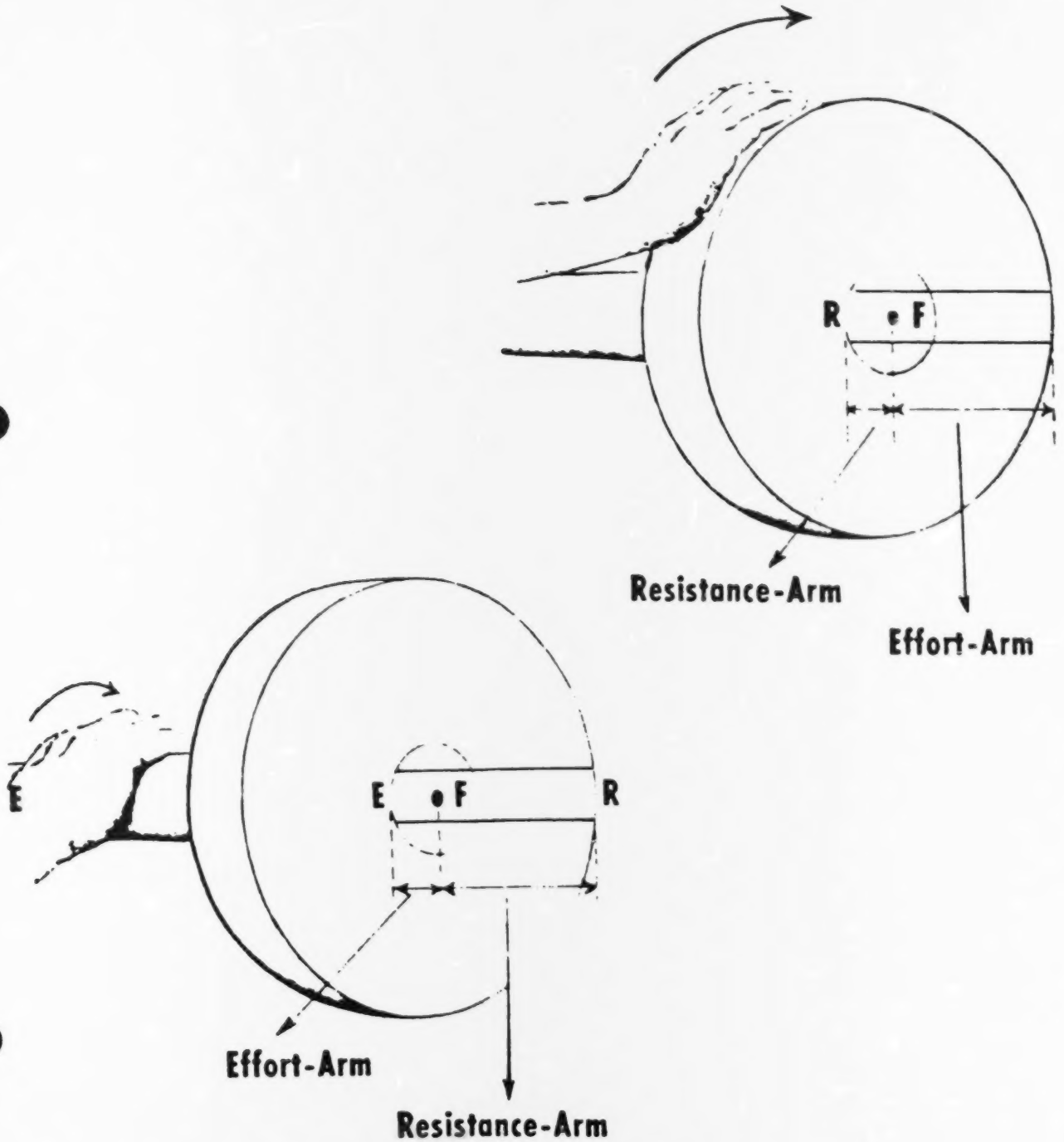


Ideal M. A. = 4

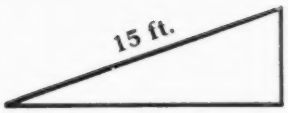


Ideal M. A. = 5

STUDY MASTER NO. 5
LESSON 12

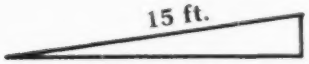


STUDY MASTER NO. 6
LESSON 12



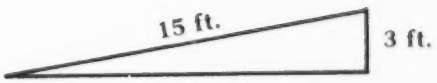
Ideal M.A. = three

$$\text{Ideal M. A.} = \frac{\text{Effort Distance}}{\text{Resistance Distance}} = \frac{15 \text{ ft}}{5 \text{ ft}} = 3$$

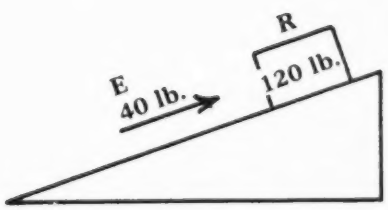


Ideal M.A. = 7 1/2

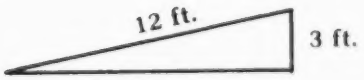
$$\text{Ideal M. A.} = \frac{\text{Effort Distance}}{\text{Resistance Distance}} = \frac{15 \text{ ft}}{2 \text{ ft}} = 7\ 1/2$$



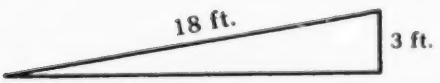
Ideal M.A. = 5



Actual M.A. = 3

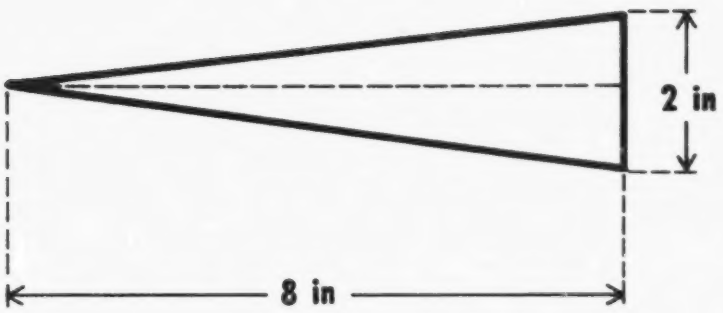


Ideal M.A. = 4



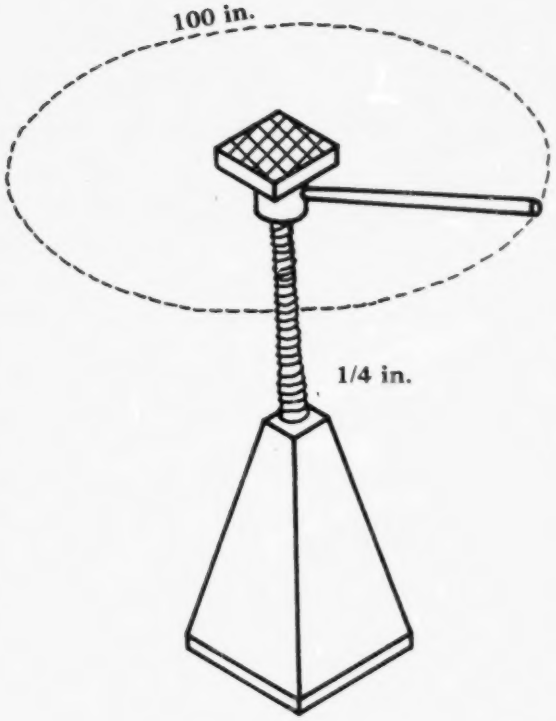
Ideal M.A. = 6

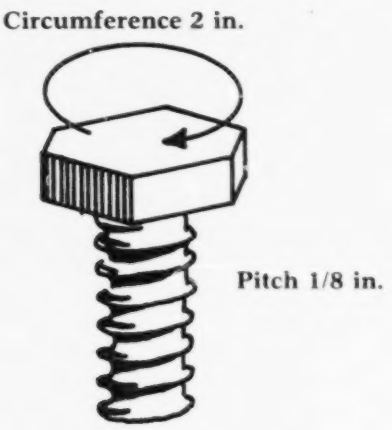
STUDY MASTER NO. 7
LESSON 12

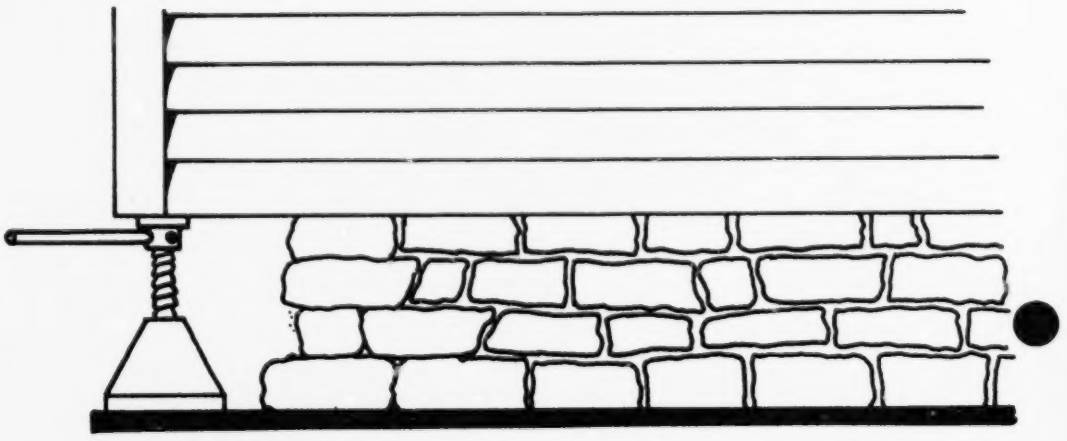


Ideal M. A. = 4

STUDY MASTER NO. 8
LESSON 12

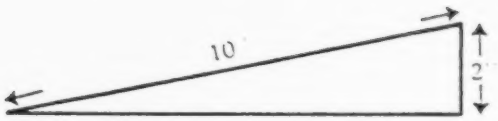




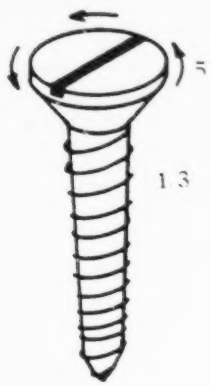


STUDY MASTER NO. 9
LESSON 12

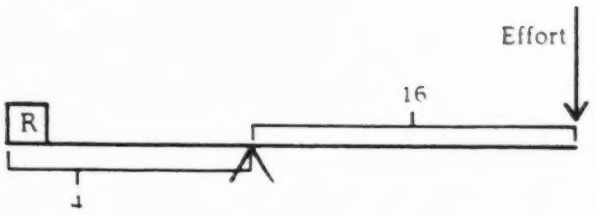
1. (M.A. = 10/2 =5)



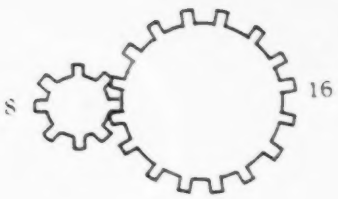
2. (M.A. = $\frac{5}{1/3}$ = 15)



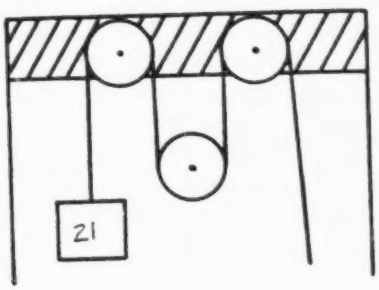
3. (M.A. = 16/4=4)



4. (M.A. 16/8=2)

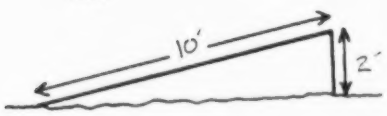


5. (M.A. = 3)

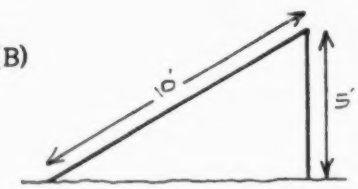


6. Which gives a greater M.A.? (A)

(A)

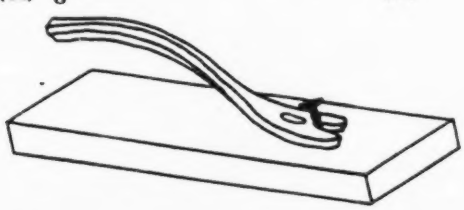


(B)

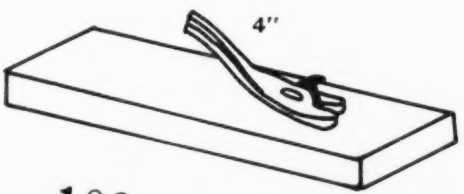


7. To make your work easier, should you use crowbar A or crowbar B ? (A)

(A) 8"



(B)



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OPTIONAL LESSONS:
(Cards 17, 18, back pages of Cards 3, 8, 9, 10, 13, 15)

As time permits in your classroom, you may pursue lessons on wind and water as energy sources. Pages 34-36 of the LEGO® teacher's guide provide suggestions. The concepts involved in these lessons have been taught in previous lessons.

Back page models from Cards 3, 8, 9, 10, 13, and 15 are not specifically designed as part of the teaching unit. Within your time constraints, you may wish to give pupils an opportunity to pursue these models as added challenges.

Extension - Enrichment - Challenges

The "Follow-Up Activities" section of the LEGO^{R} teacher's guide contains suggestions that may create challenges for pupils wishing to pursue concepts further. In addition, the following activities are offered as extension, enrichment, and challenges. Attempts have been made to include some for each learning style as described in the 4 MAT system.

Lesson 1: Stability

1. Using LEGO materials, build a platform strong and stable enough to hold a one pound bag of sand.

2. Describe a platform design that would be very strong. Construct a model of it from discarded items found in or around your home.

3. Identify through library research the factor(s) that effect stability. Demonstrate the factor(s) involved by using as many pieces of the kit as you can to build a tower as high as you can. If you use string, can you increase the towers height? What does this do to stability?

4. Make a list of people who are concerned with some dimension of structure stability.

Lesson 2: Levers and Work

1. Develop a graph of the data you collected with the white model on Card 4. Using interpolation, predict values for points in between the holes used. Encourage extrapolation to predict the effort needed if three 16 x 1 beams were used. (If the graph is parabolic rather than linear, extrapolation is more difficult.) Devise a way to prove your predictions.

2. Build an improved model of the "letter scale" shown on the back of Card 4. Describe the ways in which it has been improved.

3. Using the school environment, find examples of levers and explain which class each lever is.

4. Invent a new type of lever. Tell how it is different from the other types of levers.

Lesson 3: Friction

1. Using the picture shown on the back of Card 11, build a model so that the load can be moved in both directions.

2. Investigate the effect different surfaces have on the amount of friction present. Develop a chart which ranks the surfaces by amount of friction.

3. Research the role of lubricants in reducing friction. List specific lubricants and their uses. Why are oils produced in different "weights?" What are "synthetic" oils? How are alloys and coatings used?

4. Select a specific machine. Observe and describe the way that machine operates. Identify places where friction occurs and suggest ways it could be reduced.

5. Make imprints of the various design patterns found in athletic shoe soles. How are various brands of tennis shoes different? How do tennis shoe sales differ from aerobic shoes? . . . from running shoes? What is the reason for the differences?

6. Research the differences in tire treads. Why do drag racers use "bald" tires?

Lesson 4: Inclined Plane, Screw

1. Investigate the relationship between the slope of an inclined plane and the distance a toy car travels if allowed to roll down it.

2. Using one of the tricycle models shown on Card 10, investigate how changing the weight of the vehicle effects the distance traveled. Graph the results.

3. Research inertia. Design and conduct an experiment which investigates the relationship between friction and inertia.

4. Using LEGO^{R} materials, build a set of five stairs with a handrail. Write a set of directions telling how to do it. Could it be done with fewer components? Prove your answer.

5. Research and graph how the number of teeth or points per inch on a saw blade effect the kind of work a saw can do and the mechanical advantage of each saw.

Lesson 5: Wheels and Axles

1. There is some controversy about whether the ancient Egyptians used the wheel and axles when building the pyramids. Research this controversy. What simple machines could have been used in pyramid construction? Illustrate your findings wherever possible.

2. Compare the size of wheels used on farm or construction equipment with those used on race cars. Discuss the results if the wheels on these vehicles were the same size.

Lesson 6: Belt Transmission

1. Collect pictures of belt transmissions used in modern machines. Choose an example and suggest ways the efficiency of the transmission can be improved.

2. Research various belt designs. List advantages, disadvantages, and uses of each.

3. Design a new belt for a specific purpose. Describe its construction and uses. State how it would be an improvement over existing belts.

4. Describe the use of "idler" pulleys in belt transmissions. List values and undesirable side effects.

Lesson 7: Gears and Gear Ratios

1. Research specific kinds of gears (bevel, worm, etc.) Explain why and where they are used.

2. What happens when gears are "stripped"? Illustrate.

3. Using LEGO^{R} components, what is the greatest gear ratio you can achieve in a gear train?

4. Develop a chart which will show sizes of gears (number of teeth), rotation direction, and number of rotations. Extend the chart for at least ten rotations. Develop a computer program which will give the same information for any combination of gears.

5. Research and explain how manual and automatic transmissions differ in their use and placement of gears.

6. Research and illustrate the differences between gears on three speed, five speed, ten speed and racing bicycles. Suggest ways for improving the system.

Lesson 8: Transmission of Motion

1. Research the relationship between the pendulum and gears in a grandfather clock.

2. Research time-telling methods which do not use gears. Devise a clock-wise device of your own.

Lesson 9: Centrifugal Force

1. Develop a model which will demonstrate the relationship between radius, speed, and mass in producing centrifugal force. Explain it.

Lesson 11: Steering Mechanism

1. Research the use of "rack and pinion" in modern car steering systems. What percent uses rack and pinion? How does cost compare to parallel steering?

2. Describe the steering systems on backhoes, lift trucks, etc.? Use interview techniques as well as Holtan research methods.

3. What is the relationship of suspension systems to steering systems? Contact automobile mechanics, car dealerships, repair manuals, etc.

4. Describe the role of shock absorbers in steering systems.

Lesson 12: Mechanical Advantage

1. Describe how the efficiency of a machine is determined. Build a machine using LEGO^{R} components. Determine its efficiency. Suggest ways to improve it.

2. Develop a computer program which will compute efficiency.

3. Research and graphically demonstrate how sharpening a cutting tool increases its mechanical advantage.

TEST ITEMS: SIMPLE MACHINES, PART I

1. Which of these occurrences demonstrates work?

   a. A baby pulling a toy cart.
   b. A farmer struggling to dislodge an immovable boulder.
   c. A flagpole standing empty.

2. You have a set amount of work to do. If you increase the amount of force used, the distance that force travels must be:

   a. More.
   b. Less.
   c. The same.

3. Which requires more work:

   a. Lifting a ten pound box two feet.
   b. Lifting a five pound box three feet.
   c. Lifting a one pound box twenty five feet.

4. Oil is used in automobile engines:

   a. To reduce friction.
   b. To increase friction.
   c. To decrease mileage.

5. When you drive on a ramp from one highway to another, you are driving on:

   a. A lever.
   b. A pulley.
   c. An inclined plane.

6. One way to increase the ease with which you can split a log is to use:

   a. A hammer.
   b. A short, thick wedge.
   c. A long, thin wedge.

7. You have a choice of three egg beaters to use. All of the blades and gears are the same size; therefore, the one which will turn fastest is the one with:

   a. The smallest drive wheel.
   b. The largest drive wheel.
   c. The most chrome on the drive wheel.

8. To lift your boat most easily from the water, you would choose a crank with a:

   a. Small wheel.
   b. Medium-sized wheel.
   c. Large wheel.

9. To decrease the amount of slippage from a belt transmission, you can:

   a. Oil the belts.
   b. Cross the belts.
   c. Add a third belt.

10. You have connected an eight toothed gear and a twenty-four toothed gear. The larger gear is the drive gear; therefore, from the machine you will get:

   a. Speed.
   b. Force.
   c. Both speed and force.

11. When you connect an eight toothed gear directly to a forty toothed gear, the gears will turn:

   a. At the same rate.
   b. In opposite directions.
   c. In the same direction.

12. A baseball bat at rest on the batter's shoulder is an example of:

   a. Kinetic energy.
   b. Potential energy.
   c. No energy.

13. A baseball bat when being swung is an example of:

   a. Kinetic energy.
   b. Potential energy.
   c. No energy.

14. The movement of the windshield wipers on your car demonstrates that:

   a. Motion is always to-and-fro.
   b. Motion is solely rotary.
   c. Motion can be changed from one form to another.

15. In a washing machine, more water is "wrung" from the regular cycle than from the delicate cycle; therefore, the cycle which spins the fastest is the:

   a. Delicate cycle.
   b. Regular cycle.
   c. Both spin equally fast.

16. To more easily lift a huge load, you could use:

   a. A single fixed pulley.
   b. A block and tackle.
   c. A tackling dummy.

17. You want a sports car which will corner sharply; therefore, you buy a model which has:

   a. A small steering wheel.
   b. Parallel steering.
   c. Trapezium steering.

18. You want a screw which will turn most easily into metal; therefore, you choose one with:

    a. A small head and a large pitch.
    b. A large head and a small pitch.
    c. A head and pitch of equal size.

19. To get the greatest mechanical advantage from a lever when lifting a crate, you should place the fulcrum:

    a. As near to the crate as possible.
    b. As far from the crate as possible.
    c. As close to the effort as possible.

20. When you test a machine you built, you find its mechanical advantage is less than you expected it would be. This difference could be caused by:

    a. Slippage.
    b. Friction.
    c. Both.

Simple Machines Unit Test: Part II

Directions: Select one of these models and make it using the LEGO^R kit. You may work with one partner, but **both** partners must be able to answer questions concerning the model.

1. A model which changes one form of motion to another form. You must be able to clearly explain what you did.

2. A model which demonstrates how to raise an object from one position to a higher position. Be able to identify the parts.

3. A model which demonstrates gearing up and a model which demonstrates gearing down. Be able to explain the difference.

4. A model which uses block and tackle to lift a load. Be able to explain what would occur if fewer/more pulleys were used.

5. A model which combines several simple machines. You must be able to identify each specific simple machine you have included and tell its function.

6. A model which gives a mechanical advantage of no less than 3. You must be able to prove the mechanical advantage and tell where it occurs.

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